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The Effects of Level of Autonomy on Human-Agent Teaming for Multi-Robot Control and Local Security Maintenance

by Julia L. Wright, Jessie Y. C. Chen, Stephanie A. Quinn, and Michael J. Barnes

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Human Research and Engineering Directorate, ARL

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14. ABSTRACT

The effect of differing levels of autonomy (LOA) using a route-planning agent (RoboLeader) on human multitasking performance (convoy navigation management, target detection, and maintaining situation awareness) was evaluated using a simulated environment. Eye tracker data was used to further explain performance findings, as well as examine Operator Control Unit usage among participants. Increasing LOA improved task performance and reduced workload; however differential effects due to spatial ability (SpA) were found that indicate an optimal level of LOA. Although low SpA participants' performance improved with increasing LOA, high SpA participants had a performance decline in the highest LOA. Participants with high perceived attentional control (PAC) benefited from increasing LOA, while those with low PAC did not. Low SpA participants' SA improved in the RoboLeader conditions to nearly that of high SpA participants.

15. SUBJECT TERMS

human-agent teams, human-robot Interaction (HRI), robot teleoperation, level of autonomy (LOA), robotics control, supervisory control, unmanned vehicles, situation awareness, individual differences

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1. Introduction

The battlefield of the future will use robotic/unmanned vehicles in increasing numbers. Human operators may find themselves overwhelmed in the attempt to manage multiple robots while simultaneously performing tasks, such as local security maintenance. Prior research has shown that operators who were assigned to manage multiple robots suffered performance degradation on concurrent tasks (Chen et al., 2008). Specifically, situation awareness (SA) reduces as the size of the robot team increases, whereas cognitive resources become depleted (Chen and Barnes, 2012a; Wang et al., 2008; Wang et al., 2009), and response times increase. The increase in response times is particularly evident when switching between tasks—such as switching from a target detection task to managing convoy vehicle spacing (Squire and Parasuraman, 2010). Further, when a single operator manages multiple robots by interacting with them individually, workload increases as the number of robots increase, the number of tasks that can be successfully completed within a designated time interval decreases, and the number of system failures and accidents increase (Adams, 2009). Clearly, it is impractical and inefficient for the operator to interact with each robotic team member individually when the operator is coordinating the actions of multiple robots.

RoboLeader is an intelligent agent developed under the U.S. Army Research Laboratory's (ARL's) Director's Research Initiative and was designed to assist a human operator with managing a team of robots (Chen and Barnes, 2012a, 2012b; Snyder et al., 2010). Instead of the human operator interacting with each robot individually, the operator only interacts with RoboLeader, thus freeing cognitive resources for other tasks. The effectiveness of RoboLeader was previously investigated in three human-in-the-loop simulation experiments and was found to improve operator's mission completion times, as well as reduce their perceived workload (Chen and Barnes, 2012a, 2012b).

1.1 Level of Autonomy

This study investigates the appropriate level of autonomy (LOA) to assign to RoboLeader in a human-agent teaming task. The LOA of a system changes the dynamics of the human-agent relationship (Parasuraman and Riley, 1997; Parasuraman et al., 2000), and as discussed in Chen et al (2011), it is important for system designers to select a LOA that helps the operator maintain SA while keeping the operator engaged in the task. A LOA that is too low may increase workload, resulting in operator fatigue and decreased performance. In comparison, a too high LOA may disengage the operator, resulting in automation-induced complacency, decreased SA, and vigilance decrements (Parasuraman and Riley, 1997; Endsley, 1999; Parasuraman et al., 2000). Often a medium LOA is recommended to reduce human out-of-the-loop problems and to help maintain manual skills.

However, no LOA seems to be effective at preventing errors of commission, as these errors are also caused by factors other than complacency, and as such, tend to occur independent of LOA (Manzey et al., 2008; Reichenbach et al., 2010).

1.2 Multitasking

It is becoming commonplace to expect an operator to concurrently conduct several tasks. When switching between tasks, the primary task performance suffers when it is interrupted by a secondary task (Cummings, 2004; Monsell, 2003). Advanced preparation for a task switch may reduce the impact associated with switching, although it cannot completely negate the effect (Altmann and Trafton, 2004). Although performance may recover somewhat after switching tasks, there is a long-term negative effect on response times, as well as increased error rates (Monsell, 2003). Performance, particularly in the secondary tasks, can be improved by increasing LOA assistance (Manzey et al., 2008).

When switching between different types of tasks, the associated costs of task switching also increase (Squire et al., 2006). Task switching costs may be increased with higher LOAs, as these can lead to a less active information processing mode by the operator (Chen and Barnes, 2012a; Wickens et al., 2003), which forces the operator to regain knowledge of the state of the system before conducting the new task (Squire and Parasuraman, 2010). Interface design affects switching costs as well, particularly when managing robot teams of increasing size (Squire et al., 2006).

1.3 Individual Differences

The effects of individual differences on operator performance were also evaluated in the current study. Specifically, the effects of individual differences in perceived attentional control (PAC), spatial ability (SpA), and gaming experience on the operators' robotics control, as well as multitasking performance, were investigated.

1.3.1 Attentional Control

The relationship between perceived attentional control and multitasking performance was examined. Attentional control refers to an individual's ability to choose what they will attend to and what they will ignore (Astle and Scerif, 2009). Although there are individual differences in multitasking performance, some people are less likely to suffer performance degradation while multitasking (Rubinstein et al., 2001). There is evidence that individuals with higher PAC can allocate their attention more flexibly and effectively (Derryberry and Reed, 2002; Chen and Joyner, 2009). In Chen and Barnes (2012a), participants with higher PAC reported lower workload than did those with lower PAC.

1.3.2 Spatial Ability

Previous research has found performance differences on certain tasks between individuals with high and low SpA. Lathan and Tracey (2002) demonstrated that people with

higher SpA finished their tasks faster and had fewer errors during a teleoperation task through a maze. Lathan and Tracey suggested that military missions could benefit from selecting personnel with higher SpA to operate robotic devices. Spatial ability was also found to be a good predictor of the operator's robotics performance (Chen et al., 2008; Chen and Barnes, 2012a). In Chen and Barnes (2012a), participants with higher SpA scanned the simulated robot's video views significantly faster than those with lower SpA, resulting in more targets detected and higher SA.

1.3.3 Gaming Experience

There is evidence that, when compared to infrequent gamers, frequent video game players collaborate more with automated systems (Cummings et al., 2010), show more flexibility and efficiency in visual attention (Green and Bavelier, 2003), and have better visual memory (Green and Bavelier, 2006). Video gaming experience has also been shown to correspond with faster reaction times, improved tracking of moving targets (McKinley et al., 2011), better performance in target detection tasks, and improved SA (Chen and Barnes, 2012a, 2012b).

1.4   Current Study

In the current experiment, we simulated a multitasking environment where the operator (i.e., vehicle commander) had to supervise the routes of three vehicles (i.e., their own manned ground vehicle [MGV], an unmanned aerial system [UAS], and an unmanned ground vehicle [UGV]), and the distance separations among them while maintaining proper 360° local security around their MGV. The U.S. Army is currently developing 360° indirect-vision display capabilities to enable vehicle commanders to see their immediate environment via streaming video sent from cameras mounted outside the MGV (Elliott et al., in press). The three simulated vehicles traveled in an urban environment as a convoy, and the participant had to decide whether and how the routes for the convoy needed to change based on intelligence reports and/or environmental events (e.g., threats present, environmental hazards/obstacles), as well as pause/start vehicle movement in order to maintain assigned vehicle separation. The paradigm followed that which was previously studied by Chen and Barnes (2012a) and the participants performed the convoy management duties either manually or with assistance from RoboLeader (for the vehicle separation task only or for both vehicle separation and convoy route planning). The participants also concurrently monitored an indirect-vision display of the environment surrounding the MGV and reported any threats present in their immediate environment. Threats were identified as civilian persons or vehicles that were armed. Visual density, type, and number of threats were held constant across missions and automation levels.

1.4.1 Stated Hypothesis/Objective

This experiment manipulated the LOA of RoboLeader to assist the operator with his/her convoy management tasks. There were three levels of automation assistance: Manual (no RoboLeader assistance) and two RoboLeader levels: Semi-Autonomous (maintaining vehicle distance

/separation only) and Fully Autonomous (vehicle separation + route planning). The participants also maintained 360° local security by monitoring the two 180° indirect-vision display camera feeds (one forward, one rearward) and detecting targets when they appeared. The effects of individual differences in spatial ability, attentional control, and prior gaming experience on the operators' task performance were also investigated. Therefore, the principal objectives were (1) to determine whether increasing levels of assistance from RoboLeader improved a commander's ability to maintain 360° security and SA, (2) whether individual differences had differential effects on the commander's ability to maintain security, and (3) whether increasing levels of assistance from RoboLeader resulted in reduced workload levels and improved scan efficiency. In addition to the stated hypotheses, eye movement data was collected to evaluate how well physiological measures of workload, interest, and scan efficiency correlate with performance, SA, and subjective workload measures, and to evaluate the usability of the user interface and various camera feeds (see section 2.4.1.4 Eyetracker Data).

2. Method

2.1 Participants

Thirty individuals (21 males, 9 females, $M_{age} = 24.7$ years) from the Orlando, FL, area participated in the experiment. Participants were compensated $15/hr for their time.

2.2 Apparatus

2.2.1 Simulator

A modified version of the Mixed Initiative Experimental (MIX) Testbed was used as the simulator for this experiment (Barber et al., 2008). The RoboLeader algorithm was implemented on the MIX Testbed and it had the capability of collecting information from subordinate robots with limited autonomy (e.g., collision avoidance and self-guidance to reach target locations), making tactical decisions, and coordinating the robots by issuing commands, mapping waypoints, etc. (Snyder et al., 2010). The MIX Testbed is a distributed simulation environment for investigating how unmanned systems are used and how automation affects human operator performance. The Operator Control Unit (OCU) of the MIX Testbed (figure 1) was modeled after the Tactical Control Unit developed under the ARL Robotics Collaborative Technology Alliance.

Figure 1. Operator control unit: user interface for convoy
management and 360° tasking environment.

2.2.2 Eyetracker

A Sensomotoric Instrument (SMI) Remote Eyetracking Device (RED) was used to collect eye movement data. The SMI RED system uses an infrared (IR) camera-based tracking system and allows completely noncontact operation (SMI, 2013). Eye and head movements, which were observed at approximately 0.03° of spatial resolution and sampled at the rate of 60 Hz, along with measurement reliability data, were logged in real time and synchronized with performance data from the MIX Testbed system. Only the participants' eye gaze coordinates were measured and recorded, no video of the participants' faces was recorded. The SMI system was individually calibrated for each participant prior to each trial.

2.2.3 RoboLeader

RoboLeader was developed to assist a human operator manage a team of robots (Chen and Barnes, 2012a, 2012b; Snyder et al., 2010). RoboLeader is a mixed-initiative system; some processes are managed by RoboLeader without human interaction and some processes offer suggestions to the human operator for approval before being carried out. In the current study, there were two levels of assistance from RoboLeader: Fully Autonomous and Semi-Autonomous. In the Fully Autonomous condition, RoboLeader managed the spacing of the convoy vehicles without intervention from the human operator, suggested route changes when environmental events dictated, and then made the route changes when approved by the operator. In the Semi-Autonomous condition, RoboLeader managed the spacing of the convoy, but otherwise offered no assistance with convoy management tasks.

2.3.4 Survey and Tests

2.3.4.1 Demographics Survey

A demographics questionnaire was administered at the beginning of the training session. Information on participants' age, gender, educational level, computer familiarity, and gaming experience was collected (appendix A). Participants indicated how often they played computer

or video games (daily, weekly, monthly, every few months, rarely, never), and participants that responded "daily" or "weekly" were categorized as frequent players, while all others were infrequent. Participants also reported which types of computer games they play most often, and game type was categorized as Action or NonAction. Action games were defined as games where the majority of challenges are physical tests of skill, requiring good hand−eye coordination and quick response times, and that have a time constraint as well, so that the player does not have time for complex strategy development (Adams, 2010). Examples of game types that were classified as action are first-person shooters (FPS), fighting games, racing games and real-time strategy games. Participants that were both Frequent and Action Gamers were categorized as Frequent Action Gamers ($N = 13$), all other combinations of responses were All Others ($N = 17$).

2.2.4.2 Color Vision Test

An Ishihara Color Vision Test (using nine test plates) was administered via PowerPoint presentation. Because the RoboLeader OCU employs several colors to display the plans for the robots, normal color vision was required to interact effectively with the system. All participants had satisfactory color vision.

2.2.4.3 Attentional Control Survey

Participants' PAC was evaluated using the Attentional Control survey (Derryberry and Reed, 2002; appendix B). The Attentional Control survey consists of 21 items and measures attention focus and shifting. The scale has been shown to have good internal reliability ($\alpha = 0.88$). High/Low group membership was determined by median split of all participants' scores (PAC_{LOW} $N = 15$, PAC_{HIGH} $N = 15$).

2.2.4.4 Spatial Ability Tests

The Cube Comparison Test (SpAC) (Ekstrom et al., 1976) and the Spatial Orientation Test (SpAO) (Gugerty and Brooks, 2004) were used to assess participants' spatial ability. These two tests measure different aspects of spatial ability. The Cube Comparison Test (appendix C) estimates the ability of an individual to perceive spatial patterns and to maintain orientation with respect to objects in space. It requires participants to compare, in 3 min, 21 pairs of six-sided cubes and determine if the rotated cubes are the same or different. The score is determined by subtracting the number of incorrect responses from the number of correct responses, with higher scores indicating higher performance. High/Low group membership was determined by median split of all scores ($SpAC_{LOW}$ $N = 13$, $SpAC_{HIGH}$ $N = 17$).

The SpAO (appendix D), modeled after the cardinal direction test developed by Gugerty and his colleagues (Gugerty and Brooks, 2004), evaluates an individual's ability to reorient their imagined self. It is a computerized test consisting of a brief training segment and 32 test questions. The program automatically captures both accuracy and response time.

Individual performance scores were calculated by dividing average response time by total number correct, with higher performance indicated by lower scores. High/Low group membership was determined by median split of all scores ($SpAO_{LOW}$ $N = 15$, $SpAO_{HIGH}$ $N = 15$).

2.2.4.5 NASA-TLX

The NASA-TLX (appendix E) is a self-report measure of perceived workload. The computerized version of the NASA-TLX questionnaire was administered after each trial to evaluate perceived workload (Hart and Staveland, 1988). Definitions of each subscale were provided to the participants as a document that they could refer to as needed while completing the questionnaire.

2.2.4.6 Usability and Trust Survey

Participants' perceived usability of RoboLeader and overall trust in the system were evaluated using the Usability and Trust Survey from Chen and Barnes (2012a). Trust questions were modified from Jian et al (2000) Trust Between People and Automation questionnaire. The usability and trust survey consisted of 22 questions rated on a scale of 1 to 7 (appendix F). Participants were instructed that, for the purpose of the survey, "RoboLeader" referred to the Fully Autonomous condition, while "RoboLeader display" referred to the OCU as a whole.

2.3   Procedure

After being briefed on the purpose of the study and signing the informed consent form, participants completed the demographics questionnaire, the Attentional Control Survey, received a brief Ishihara Color Vision Test, and completed the two spatial ability tests.

Participants then received training and practice on the tasks needed to complete the experimental session. Training was self-paced and delivered via PowerPoint[*] slides. The slides explained the elements of the OCU, steps for completing various tasks, and included several practice exercises for performing the robotic control tasks. The training session lasted approximately 1 h. Before proceeding to the experimental session, participants had to demonstrate that they could perform the tasks without any help. All participants demonstrated adequate mastery of the system before proceeding with the study.

The experimental session lasted approximately 1.5 h and began immediately after the training session. Each experimental session had three scenarios (missions 1, 2, and 3), which were presented in this order for all participants. Using a Latin Square design, each scenario was randomly assigned an automation condition (i.e., Manual, Semi-Autonomous, or Fully Autonomous), so that each participant completed all three scenarios and experienced all three automation levels. Automation condition assignment to scenario was counter-balanced to avoid order effects. Scenarios were self-paced, but were designed to take 25–40 min to complete. There was a 2 min break between the experimental scenarios.

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[*]PowerPoint is a trademark of Microsoft Corp.

During the scenarios, participants supervised a convoy of three vehicles (i.e., a UAS, a UGV, and their MGV) moving from point A to point B, while maintaining specified distances between the three vehicles. Each scenario had a route mapped for the vehicles when the scenario began, and the participants' task was to modify the routes as needed based on environmental or intelligence "events." Several events occurred during each scenario that required revision to the convoy's route. These events could be in the form of intelligence reports that the human operator received from the intelligence network or environmental hazards such as fire or road blockages they would encounter en route. Once an event transpired, the participants had to notice and acknowledge that the event occurred, and then respond accordingly. In the Fully Autonomous condition, RoboLeader recommended plan revisions for the events by presenting the new waypoints on the map, and the operator could accept the recommendation, or reject and modify the route, as they deemed necessary. In the Semi-Autonomous and Manual conditions, the participants manually modified the waypoints for the lead ground vehicle (i.e., UGV) when the convoy's route needed to be changed.

Participants were advised of optimal spacing requirements for between vehicle distances, and part of their convoy management duties were to supervise and maintain these required distances. Vehicle separation was accomplished by pausing and restarting individual vehicle movement, which allowed trailing vehicles to catch up to lead vehicles or allowed lead vehicles to increase distance from trailing vehicles. In the RoboLeader conditions (Semi-Autonomous and Fully Autonomous), the distance separations among the vehicles were maintained automatically based on the vehicles' own leader−follower algorithms.

In addition to the convoy management duties, participants had to maintain 360° local security surrounding their own MGV by simultaneously monitoring the UGV forward camera feed and the MGV's two 180° indirect-vision displays (one forward view, one rearward view) to detect hostile targets in the immediate environment. Once a hostile target was detected, the participants would "laze" the target by clicking on the target using the mouse. An icon representing the "lazed" insurgent would then be displayed on the map. Hostile targets were defined as armed civilian individuals or vehicles. Friendly dismounted soldiers and unarmed civilians were present in the simulated environment to increase the visual noise present in the target detection tasks. Detection difficulty was balanced within each scenario, with some targets only visible upon approach, some only visible in the rear camera feed, and some visible both approaching and after passing.

Each scenario contained five SA queries (appendix G), which were triggered based on time progression (i.e., 3 min into the scenario, and then at 4 min intervals for the remainder of the trial). When an SA query appeared, the OCU screen went blank, the simulation paused, and the SA query was displayed on the screen. Participants then wrote their response to the query on the answer sheet for that scenario (appendix H). After participants responded to the SA query, they clicked the "Continue" button on the screen for the SA screen to disappear, and the simulation resumed.

Participants assessed their perceived workload immediately after each experimental scenario using the computerized version of the NASA-TLX. Following completion of all three scenarios, participants evaluated the usability of the RoboLeader system by completing the Usability/Trust Questionnaire (Jian et al., 2000). Participants were then debriefed by the experimenter and dismissed.

2.4   Experimental Design and Performance Measures

This study was a mixed within-between subject design, with Level of Autonomy (Manual [no RoboLeader], Semi-Autonomous, and Fully Autonomous) as the within-subject variable and individual difference factors such as spatial ability, attentional control, and gaming experience as the between-subjects variables. Dependent measures were the numbers of targets identified, false alarms (FAs), the operators' SA of the mission environment, and perceived workload.

2.4.1 Dependent Measures

2.4.1.1 Target Detection

Target detection performance has been shown to be related to spatial ability (Chen and Joyner, 2009; Chen and Barnes, 2012a), possibly due to improved scanning abilities (Thomas and Wickens, 2004). Each scenario contained 30 targets; however, participants were only scored on targets that were in close proximity to their chosen route. Target detection performance was calculated by dividing the number of targets correctly identified by the total number of targets that were available to the participant for detection. FAs were also examined as a measure of interest, as the number of FAs should increase as cognitive workload increases. Each scenario had several hundred potential distractors (noise); however, there were very few reported FAs across all conditions and scenarios, which would result in FA Rates so small as to be indistinguishable from one another using the Signal Detection Theory formula. Because of this, the actual number of reported FAs is used in all calculations.

2.4.1.2 Situation Awareness

Situation awareness is the perception and comprehension of the elements within one's environment and the projection of their future states (Endsley, 1995), and is therefore essential to appropriate decision-making and supervisory control (Chen et al., 2011). Multitasking divides an individual's attention, making it difficult to maintain appropriate levels of SA when switching between tasks (Cummings, 2004). Chen and Barnes (2012a) found participants with higher SpA and experienced gamers maintained higher SA than those with low SpA and infrequent gamers.

2.4.1.3 Workload

Vigilance tasks, such as maintaining local security (target detection tasks), are particularly demanding of cognitive resources. As resources become limited, attentional effort is reduced and mental workload increases (Warm et al., 1996; Warm et al., 2008). Targets that are less salient or randomly placed in the environment further increase the demands of the task on the operator,

increasing workload even more (Warm et al., 1996). Increased workload causes the operator to rely on the automation more, resulting in an operator "out of the loop" situation. This causes the operators to miss errors and rely on the system to conduct tasks with little or no supervision (Ruff et al., 2002). Higher levels of automation typically reduce operator workload, resulting in improved SA and change detection accuracy as long as the operator is engaged in the tasks that are automated (Parasuraman et al., 2009). Persons with high PAC have been found to be more resilient in multitasking situations than those with low PAC, performing better even during more challenging situations and on secondary tasks (Chen and Barnes, 2012a; Chen and Joyner, 2009).

2.4.1.4 Eyetracker Data

2.4.1.4.1 Glances: Number and Duration

A glance (or dwell) is defined as one visual visit in a predefined area, from entry to exit (Holmqvist et al., 2011). The number of glances in a predefined area is positively correlated to instrument difficulty (Chisholm et al., 2008), as well as semantic informativeness (Loftus and Mackworth, 1978).

Glance duration (aka dwell time) is defined for purposes of this study as beginning at the time the area of interest (AOI) is first fixated on by an individual until the end of the last fixation in the AOI for one visit. This includes the summation of all fixations and saccades that occur during each glance. Glance duration is one of the most widely used measures in usability studies (Jacob and Karn, 2003), most likely due to its versatility. Glance duration has been found to be indicative of several negative performance situations, such as difficulties extracting information (Goldberg and Kotval, 1999), poor SA (Hauland, 2008), and task uncertainty (Ottati et al., 1999). However, it can also indicate higher interest, the informativeness of an object (Friedman and Liebelt, 1981), and when a conscious choice is impending (Shimojo et al., 2003).

2.4.1.4.2 Fixations

Fixations are low-velocity eye movements that correspond to a person staring at a particular point. They contain small randomly drifting eye movements and quick adjustments to keep a particular target centered. The SMI eye tracking system detects fixations by applying a maximum-movement threshold amount for a minimum period of time (SMI, 2011). The number of fixations is also frequently seen in usability studies and is positively correlated with glance duration (Jacob and Karn, 2003). The number of fixations in a predefined area has been found to be positively correlated to semantic importance (Jacob and Karn, 2003), search difficulty (Ehmke and Wilson, 2007), and encoding memory (i.e., more fixations on an object result in better memory for that object; Tatler et al., 2005). Fixations are negatively correlated with search efficiency (Goldberg and Kotval, 1999), experience (Reingold et al., 2001) and increased mental workload (Van Orden et al., 2000). Studies on expertise have indicated that experts make more fixations of shorter duration than novices, demonstrating improved search efficiency (Kasarskis et al., 2001; Williams et al., 1994).

2.4.1.4.3 Blink Rate

Blink rate is defined as the number of blinks per second. Blink rate tends to increase with time on task, fatigue, time of day (Stern et al., 1994), and increased mental workload (Van Orden et al., 2000).

2.4.1.4.4 Saccade Amplitude

The amplitude of a saccade is the distance travelled by a saccade from its onset to its end. It can be measured either in visual degrees or in pixels (Holmqvist et al., 2011). Saccade amplitude tends to be idiosyncratic, and as such, it was used only as a repeated measures measure in this study. Shorter saccadic amplitudes are correlated with difficulty in search tasks (Zelinsky and Sheinberg, 1997), and increased mental workload (May et al., 1990; Recarte and Nunes, 2003). They are also indicative of density of visual information in the area surrounding fixation (Tatler et al., 2006).

2.4.1.4.5 Pupil Diameter

Pupil size is raw data that is sampled throughout the recording of the eye tracking system. It is sensitive to lighting changes in the stimulus, view angles (i.e., gaze direction), distance to the screen and eyelid closure. Pupil size is measured by imposing an ellipse over the dark area of the pupil and reporting the vertical and horizontal axis lengths; this is sometimes reported as vertical and horizontal diameters. The horizontal axis measurement is less sensitive to artifacts due to eyelid closure than the vertical axis measurement (Holmqvist et al., 2011). Increase in pupil diameter has been found to be positively correlated with increased mental workload (Van Orden et al., 2000; Van Orden et al., 2001; Iqbal et al., 2004), and heightened interest (Kang et al., 2009).

2.4.2 Operator Control Unit and Areas of Interest

The OCU screen was divided into 14 AOIs (figure 2). AOIs were defined primarily by their function, and some AOIs were then subdivided based on screen position and size. The central AOIs were expected to have the most fixations and dwells, as orienting the eye on a central portion of the screen appears to allow for better early information intake and responsiveness (Tatler, 2007; Fehd and Seiffert, 2010). The number of fixations, number of glances, and average glance duration for each AOI were gathered and analyzed, together with target detection performance and workload ratings to investigate utility of AOI content and placement. Participants' scanning behavior and efficiency was also examined.
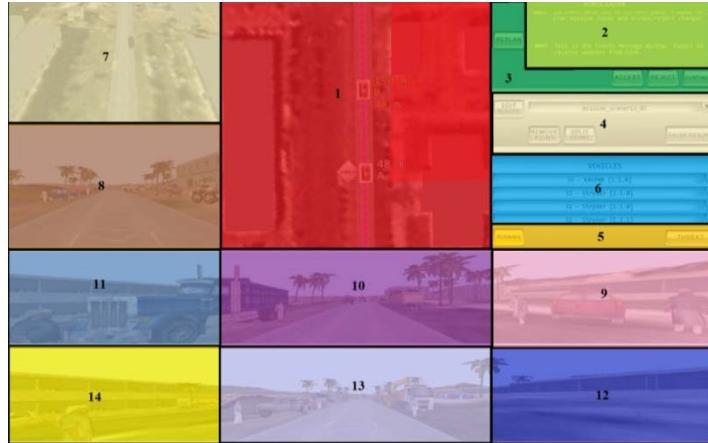
Figure 2. OCU screen divided into areas of interest.

3. Results

Repeated measures ANOVAs were used to evaluate the effect of LOA on the dependent variables, $\alpha = .05$. Mixed within-between subjects ANOVAs were used to evaluate the influence of individual difference factors on the dependent measures across three LOA, $\alpha = .05$. Findings were reported as significant when $p < .050$, marginally significant when $p < .075$. Pairwise comparisons were then used to explore specific differences across condition levels when significant results were found.

The effect of LOA on eye behavior measures was evaluated using within-subjects ANOVAs. Relationships between eye behavior measures and DVs (SA, Workload, and Usability) were examined using correlations. Mixed within-between subjects ANOVAs were used to evaluate the influence of individual difference factors on eye behavior measures (Fixation Count, Average Fixation Duration, and Pupil Diameter) across three LOA, $\alpha = 0.05$. No between-subjects evaluations were performed on Blink Rate or Saccade Amplitude, as these measures tend to be idiosyncratic. Pairwise comparisons were then used to explore specific differences across condition levels when significant results were found. When *2-tailed* results are reported, $p < 0.050$ is reported as significant, $p < 0.090$ is moderately significant.

The Chi-Square Test for Independence was used to evaluate the relationship between the independent variables (Gaming Freq/Action, PAC, SpAC and SpAO). The procedure used a 2×2 design, and the Yates' Correction for Continuity was used to control for over-estimation of the 2×2 table. All IVs were found to be independent of one another.

Participant 6 had a missing score for NASA-TLX (Semi-Autonomous condition); this was replaced with the average of their scores for the Fully Autonomous and Manual missions. As evidenced by other cases, the semi-autonomous score typically falls midway between the other

two scores, so averaging them appears to be an appropriate method to allow us to keep the data for this participant.

Several DVs (i.e., FAs, Total Pause Time, Total Simulation Time, and SA) had extreme outliers that resulted in skewed or kurtotic distributions. According to Tabachnick and Fidell (2007, pg. 77), an acceptable method to reduce the influence of univariate outliers is to simply replace the extreme value with a value that is one unit larger (or smaller) than the next most extreme score, thus reducing their influence while maintaining their relation to the rest of the data. Univariate outliers were handled in this manner for all performance DVs. Although participant 33's data is not technically a univariate outlier (as their scores were extreme outliers on two measures (Fully Autonomous FAs and Manual SA), the two measures are not directly related and adjusting those values using the univariate method should not have a detrimental effect on the whole.

When the eyetracker data was evaluated for assumptions, it was found that multiple steps were often required to sufficiently clean the data. When extreme outliers (>3 SD) were encountered in the first analysis, they were removed and the data re-assessed. Any outliers identified after the initial cleaning were considered for correction via the Tabachnick and Fidell (2007) method. No further data transformations or manipulations were required.

3.1 Performance Measure Findings

Overall main effects are summarized in table 1.

Table 1. Mean operator task performance and workload assessments.

Measure	Manual	Semi	Full	Main Effects
Target Detection % detected (SD)	54.6 (13.3)	65.3 (14.1)	63.5 (12.0)	Manual < Semi ($p < 0.001$) Manual < Full ($p = 0.001$)
False Alarms # Reported (SD)	2.43 (1.85)	3.23 (2.10)	2.40 (1.65)	Manual < Semi ($p = 0.058$) Semi > Full ($p = 0.047$)
Situation Awareness % Correct (SD)	70.7 (3.9)	76.0 (3.4)	76.7 (3.7)	—
Workload NASA-TLX Score (SD)	69.09 (14.13)	55.24 (11.54)	47.49 (19.21)	Manual > Semi ($p < 0.001$) Manual > Full ($p < 0.001$) Semi > Full ($p < 0.001$)

3.1.1 Target Detection Performance

3.1.1.1 LOA

There was a significant difference in Target Detection Performance across three LOAs, Wilks' λ = 0.583, F (2, 28) = 10.007, $p = 0.001$, *partial* η^2 = 0.417. Participants detected significantly fewer targets in the Manual condition ($M = 54.5\%$), than in the Semi-Autonomous condition ($M = 65.3\%$, $\Delta M = 10.8\%$, $p < 0.001$), or in the Fully Autonomous condition ($M = 63.5\%$, $\Delta M = 8.9\%$, $p = 0.001$), figure 3.

Figure 3. Target detection performance across LOAs.

3.1.1.2 SpAC

There was not a significant interaction between SpAC and LOA on Target Detection Performance, Wilks' $\lambda = 0.991$, $F(2, 27) = 0.128$, $p = 0.881$, *partial $\eta^2 = 0.009$*. There was no significant between-subjects effect for SpAC on Target Detection, $F(1, 28) = 0.284$, $p = 0.598$, *partial $\eta^2 = 0.010$*.

3.1.1.3 SpAO

There was a significant interaction between SpAO and LOA on Target Detection Performance, Wilks' $\lambda = 0.770$, $F(2, 27) = 4.025$, $p = 0.030$, *partial $\eta^2 = 0.230$* (figure 4). All participants benefitted from automation assistance in the RoboLeader conditions. Participants with high SpAO scores showed greatest improvement in the Semi-Autonomous condition, with their scores in the Fully Autonomous condition being similar to those with low SpAO scores. Each increasing LOA helped the low SpAO participants improve their performance on the target detection task, with performance in the Fully Autonomous condition being similar to those with high SpAO.
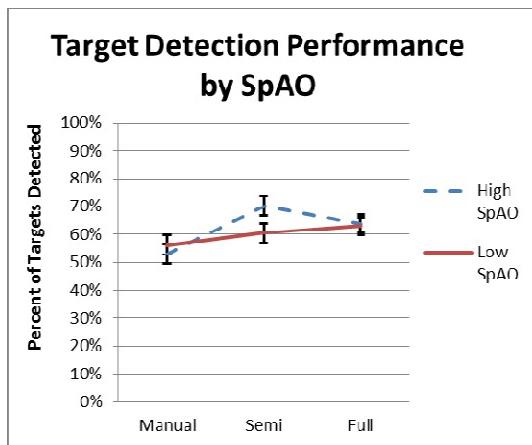
Figure 4. Target detection performance by SpAO, across LOAs.

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3.1.2 False Alarms

3.1.2.1 LOA

There was no significant difference in reported FAs due to LOA, Wilks' $\lambda = 0.834$, $F_{(2, 28)}$ = 2.786, $p = 0.079$, *partial η^2 = 0.166*. Participants reported more FAs in the Semi-Autonomous condition ($M = 3.233$) than in either Manual ($M = 2.433$, $\Delta M = -0.800$, $p = 0.058$) or Fully Autonomous ($M = 2.400$, $\Delta M = -0.833$, $p = 0.047$); however, the overall ANOVA differences did not reach significance (figure 5).
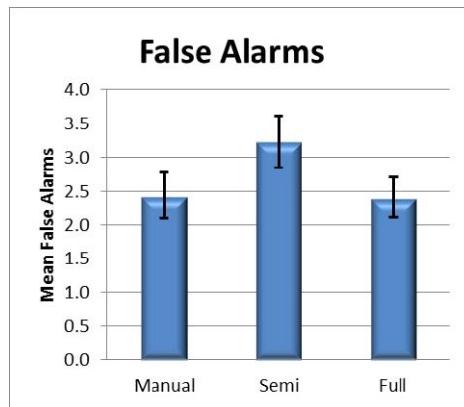
Figure 5. Mean FAs by LOA.

3.1.3 Situation Awareness

3.1.3.1 LOA

There was no significant difference in SA scores due to LOAs, Wilks' $\lambda = 0.941$, $F_{(2, 28)}$ = 0.879, $p = 0.427$, *partial η^2 = 0.059*.

3.1.3.2 SpAC

There was not a significant interaction between SpAC and LOA on SA, Wilks' $\lambda = 0.971$, $F_{(2, 27)} = 0.403$, $p = 0.672$, *partial η^2 = 0.029*. There was no significant between-subjects effect for SpAC on SA scores, $F_{(1, 28)} = 0.001$, $p = 0.971$, *partial η^2 = 0.000*.

3.1.3.3 SpAO

There was a significant interaction between SpAO and LOA on SA, Wilks' $\lambda = 0.767$, $F_{(2, 27)}$ = 4.103, $p = 0.028$, *partial η^2 = 0.233* (figure 6). Participants with high SpAO maintained higher SA across LOA than those with lower SpAO, and scored higher on the SA task during the Manual condition (84.0% correct) than those with lower SpAO (57.4% correct). Although RoboLeader helped those with low SpAO perform better on the SA task in both Semi- and Fully Autonomous conditions; it did not appear to benefit those with high SpAO.
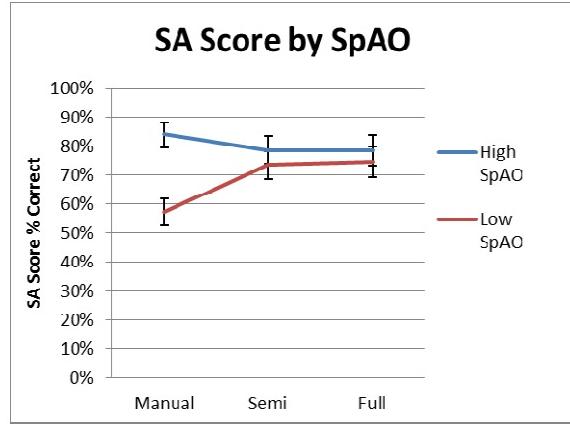
Figure 6. SA scores by SpAO, across LOAs.

3.1.3.4 Gaming Experience

There was no significant interaction between Gaming Experience and LOA on SA, Wilks' $\lambda =$ 0.842, F (2, 27) = 2.536, $p = 0.098$, *partial η^2 = 0.158*. There was a significant between-subjects effect for Gaming Experience on SA, F (1, 28) = 4.523, $p = 0.042$, *partial η^2 = 0.139*, with Frequent Action Gamers scoring significantly higher on SA measures in the Manual and Fully Autonomous conditions (figure 7).
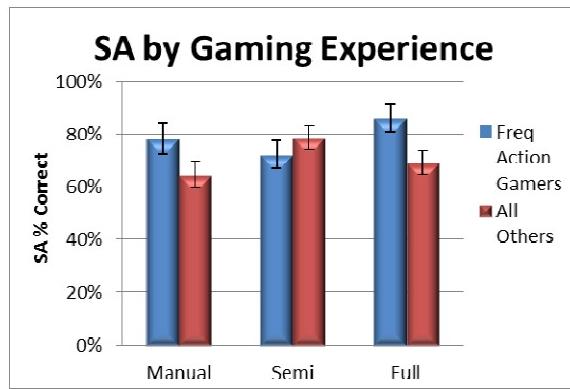
Figure 7. SA scores by gaming experience, across LOAs.

3.1.4 Perceived Workload

3.1.4.1 LOA

There was a significant difference in Perceived Workload across three LOAs. Participants reported a significantly higher level of perceived workload in the Manual condition ($M = 69.09$) than in the Semi-Autonomous ($M = 55.24$, $\Delta M = 13.850$, $p < 0.001$) and Fully Autonomous ($M = 47.49$, $\Delta M = 21.60$, $p < 0.001$) conditions, and a significantly higher level in the Semi-Autonomous condition than in the Fully Autonomous condition ($\Delta M = 7.75$, $p = 0.004$), Wilks' $\lambda = 0.354$, F (2, 28) = 25.500, $p < 0.001$, *partial η^2 = 0.646* (figure 8).

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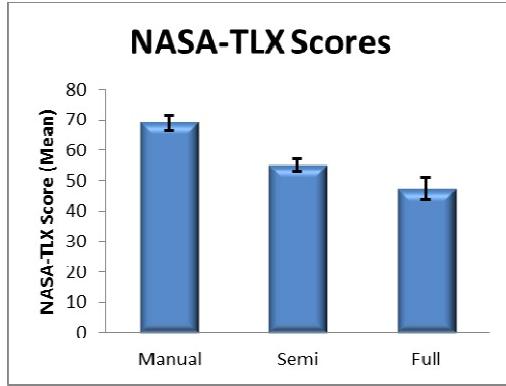
Figure 8. Perceived workload (NASA-TLX scores) across LOAs.

3.1.4.2 PAC

There was no significant interaction between PAC and LOA on Perceived Workload, Wilks' $\lambda = 0.989$, $F(2, 27) = 0.151$, $p = 0.860$, partial $\eta^2 = 0.011$. There was no significant between-subjects effect for PAC on Perceived Workload, $F(1, 28) = 0.082$, $p = 0.777$, partial $\eta^2 = 0.003$.

3.2 Eyetracker Findings

3.2.1 Fixations: Count and Duration

3.2.1.1 LOA

Fixation Count was significantly lower for Manual condition than for Semi- and Fully Autonomous conditions, Wilks' $\lambda = 0.578$, $F(2, 24) = 8.775$, $p = 0.001$, partial $\eta^2 = 0.422$ (figure 9a). Number of Fixations was significantly lower in the Manual condition ($M = 4384$) than in the Semi-Autonomous ($M = 5067$, $\Delta M = 682$, $p < 0.001$) or Fully Autonomous ($M = 5007$, $\Delta M = 623$, $p = 0.001$) conditions (figure 9a). Average Fixation Duration was significantly higher in the Manual condition ($M = 246.90$) than in the Fully Autonomous condition, $M = 234.63$, $\Delta M = 12.27$, $p < 0.05$ (figure 9b).
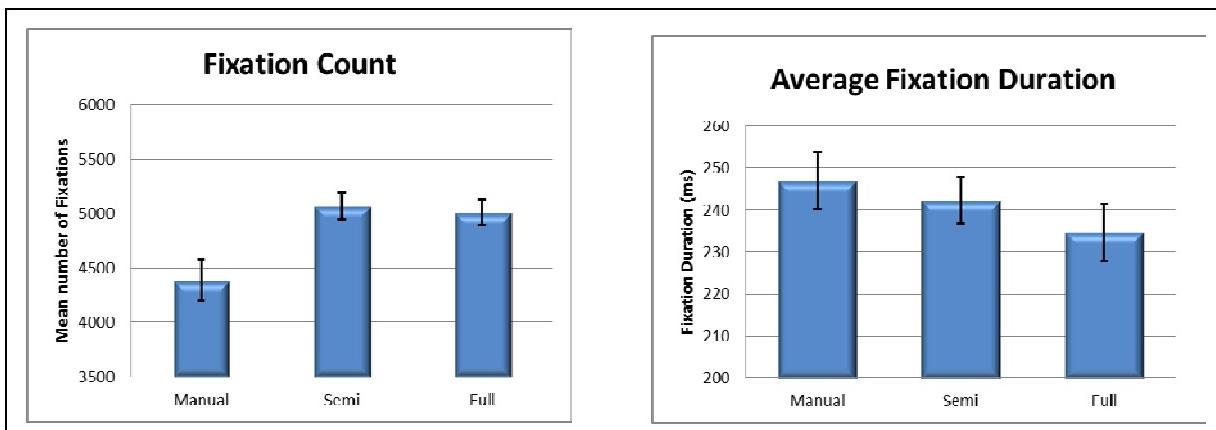
Figure 9. Fixation count (a) and average fixation duration (b) by LOA.

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3.2.1.2 Perceived Workload (NASA-TLX)

There was a significant correlation between Fixation Count and Perceived Workload for the Manual condition, $r = 0.470$, $p = 0.009$, *2-tailed* (table 2); however, Fixation Count did not correlate with Perceived Workload in either of the RoboLeader conditions, nor did Fixation Duration correlate with Workload in any condition.

3.2.1.3 SA

Fixation Count was negatively correlated with SA score for the Semi-Autonomous condition, $r = -0.435$, $p = 0.021$, *2-tailed* (table 1), but had a moderate, positive correlation for Manual ($r = 0.311$, $p = 0.095$, *2-tailed*) and Fully Autonomous ($r = 0.331$, $p = 0.085$, *2-tailed)* conditions. Average Fixation Duration did not correlate with SA scores in any condition.

3.2.1.4 Usability Rating

Fixation Count and Average Fixation Duration did not correlate with Usability ratings in any condition.

Table 2. Correlations for fixation count and fixation duration, and performance measures.

| | Fixation Count | | | | | | Fixation Duration | | | | | |
| | Manual | | Semi | | Full | | Manual | | Semi | | Full | |
	r	Sig.	r	Sig.	r	Sig.	r	Sig.	r	Sig.	r	Sig.
NASA-TLX	0.470[a]	0.009	0.070	0.722	0.272	0.162	0.231	0.220	0.185	0.329	−0.006	0.975
SA Scores	0.311	0.095	−0.435[b]	0.021	0.331	0.085	0.239	0.204	0.119	0.530	−0.257	0.170
Usability	−0.052	0.785	0.068	0.732	−0.123	0.534	−0.058	0.759	−0.005	0.978	0.102	0.591

[a]Correlation is significant at the 0.01 level (2-tailed)
[b]Correlation is significant at the 0.05 level (2-tailed)

3.2.1.5 Individual Difference Factors

There were no significant interactions or main effects of SpAC, SpAO, or Gaming Experience on Fixation Count or Average Fixation Duration.

3.2.1.6 PAC

There was no significant interaction between PAC and LOA on Fixation Count, Wilks' $\lambda = 0.958$, $F (2, 27) = 0.498$, $p = 0.614$, *partial* $\eta^2 = 0.042$. There was a marginally significant between-subjects effect for PAC on Fixation Count, $F (1, 28) = 3.747$, $p = 0.065$, *partial* $\eta^2 = 0.135$, (figure 10). Participants with low PAC had more Fixations than those with high PAC, across all LOAs.
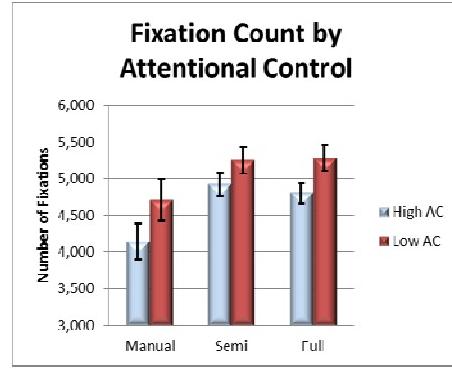
Figure 10. Number of fixations by PAC,
across LOAs.

There was not a significant interaction between PAC and LOA on Average Fixation Duration, Wilks' $\lambda = 0.987$, $F (2, 27) = 0.173$, $p = 0.842$, *partial* $\eta^2 = 0.013$. There was no significant between-subjects effect for PAC on Average Fixation Duration, $F (1, 28) = 0.872$, $p = 0.358$, *partial* $\eta^2 = 0.030$.

3.2.2 Blink Rate

3.2.2.1 LOA

There was no significant difference in Blink Rate across three LOAs, Wilks' $\lambda = 0.841$, $F (2, 24) = 2.451$, $p = 0.106$, *partial* $\eta^2 = 0.159$. Blink Rate for Manual condition ($M = 14.20$) was higher than for Semi-Autonomous ($M = 11.02$, $\Delta M = 3.183$, $p = 0.041$), or Fully Autonomous ($M = 10.99$, $\Delta M = 3.206$, $p = 0.061$) (figure 11).
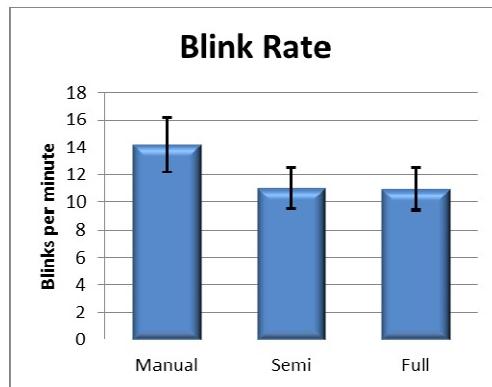
Figure 11. Blink rate by LOA.

3.2.2.2 Performance Measures

Blink Rate was not correlated with any Performance Measures (table 3).

Table 3. Blink rate correlations with performance measures.

| | Blink Rate | | | | | |
| | Manual | | Semi | | Full | |
	r	Sig.	r	Sig.	r	Sig.
NASA-TLX	0.072	0.706	−0.033	0.865	−0.189	0.317
SA Scores	−0.146	0.441	0.113	0.552	−0.142	0.455
Usability	0.089	0.640	−0.018	0.926	0.052	0.784

3.2.3 Saccade Amplitude

3.2.3.1 LOA

The average Saccadic Amplitude was significantly shorter for Semi-Autonomous condition ($M = 7.800$) than Manual ($M = 10.633$, $\Delta M = 2.833$, $p = 0.041$), and shorter but not significantly so for Fully Autonomous ($M = 11.500$, $\Delta M = 3.700$, $p = 0.252$), Wilks' $\lambda = 0.809$, $F(2, 28) = 3.295$, $p = 0.052$, $partial\ \eta^2 = 0.191$ (figure 12).
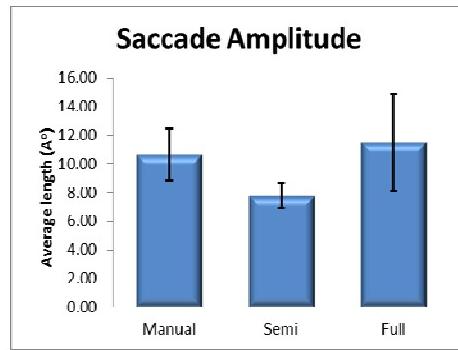
Figure 12. Average saccade amplitude by LOA.

3.2.3.2 Perceived Workload

Perceived workload was negatively correlated with participants' average saccade amplitude in the Manual and Semi-Autonomous conditions, but was not significant in the Fully Autonomous condition (table 4).

Table 4. Saccade amplitude correlations with performance measures.

| | Saccade Amplitude | | | | | |
| | Manual | | Semi | | Full | |
	r	Sig.	r	Sig.	r	Sig.
NASA-TLX	−0.425[*]	0.019	−0.342	0.064	−0.146	0.441
SA Scores	−0.310	0.095	0.108	0.571	−0.023	0.904
Usability	0.140	0.461	0.158	0.404	0.220	0.242

3.2.4 Pupil Diameter

3.2.4.1 LOA

The average Pupil Diameter for Manual condition ($M = 14.667$) was significantly larger than for Semi-Autonomous ($M = 14.133$; $\Delta M = 0.533$, $p = 0.007$), and Fully Autonomous ($M = 13.800$; $\Delta M = 0.867$, $p = 0.002$); Wilks' $\lambda = 0.687$, $F(2, 28) = 6.372$, $p = 0.005$, *partial* $\eta^2 = 0.313$ (figure 13).
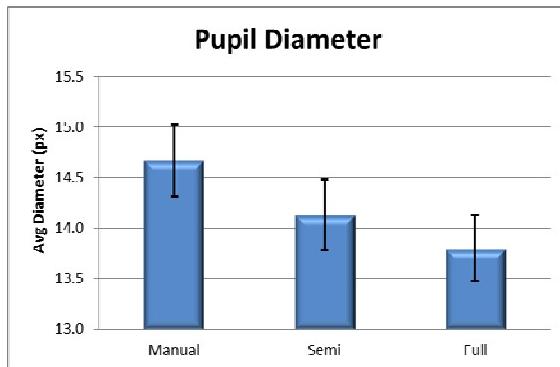
Figure 13. Average pupil diameter by LOA.

3.2.4.2 Performance Measures

Pupil Diameter was not correlated with any Performance Measures (table 5).

Table 5. Average pupil diameter correlations with performance measures.

| | Average Pupil Diameter | | | | | |
| | Manual | | Semi | | Full | |
	r	Sig.	r	Sig.	r	Sig.
NASA-TLX	0.007	0.969	-0.190	0.314	−0.032	0.866
SA Scores	−0.208	0.270	0.289	0.121	−0.187	0.322
Usability	0.010	0.958	−0.198	0.293	−0.170	0.368

3.2.4.3 PAC

No significant interaction was found between PAC and LOA on Pupil Diameter, Wilks' λ = 0.847, $F(2, 27) = 2.445$, $p = 0.106$, partial $\eta^2 = 0.153$, ns.

There was a marginally significant effect of PAC on Average Pupil Diameter across three LOAs, $F(1, 28) = 3.899$, $p = 0.058$, partial $\eta^2 = 0.122$, (figure 14). Average Pupil Diameter for participants with low PAC was consistent across all mission conditions, while Average Pupil Diameter for participants with high PAC was greatest in the Manual condition, smaller in the Semi-Autonomous condition and smallest in the Fully Autonomous condition, indicating higher mental workload in the lower levels of automation conditions.
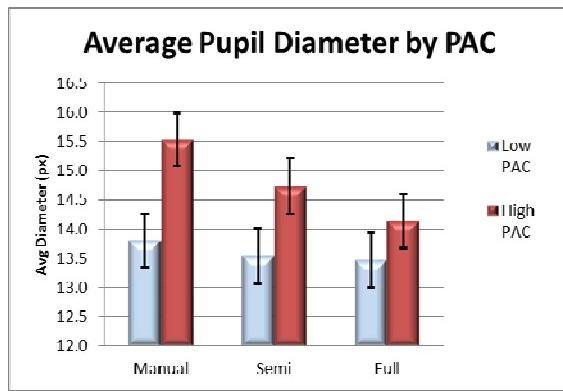
Figure 14. Pupil diameter by PAC, across LOAs.

3.3 Operator Control Unit Usability Analysis

3.3.1 AOI Analysis

Each AOI (see figure 2) was evaluated on a number of measures relating to how useful the participant(s) found that particular AOI to be, and how its usage related to overall performance in the Target Detection Task and number of FAs reported. Additionally, AOI usage was examined for differential usage based on individual difference factors. General findings are included in this section (figure 15); specific results by AOI are reported in appendix I.

3.3.1.1 Target Detection Performance

Average Fixation Duration in AOI 8 (UGV Camera Feed) was predictive of performance on the Target Detection Task in the Fully Autonomous condition; however, it was not predictive of task performance for any other AOI or any other LOA (appendix I, table 9).
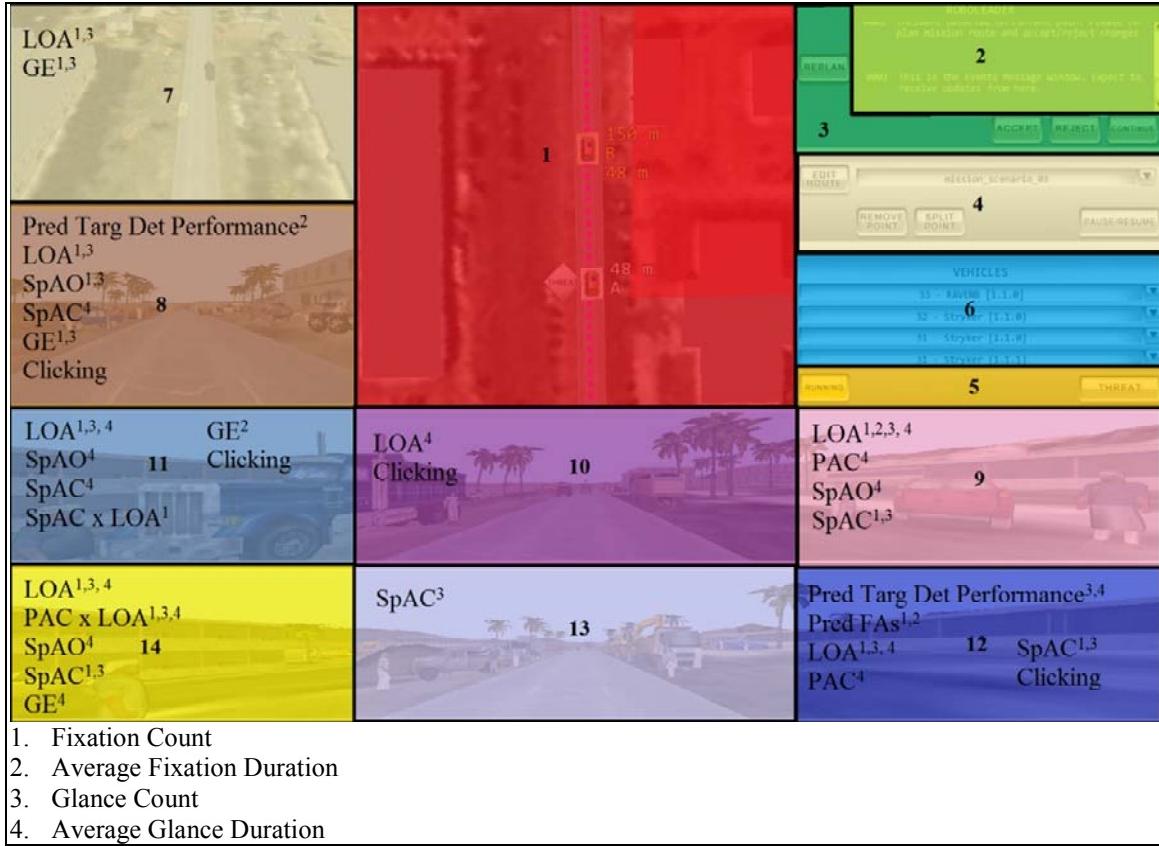
Figure 15. AOI significant findings, mapped onto OCU.

3.3.1.2 False Alarms

Fixation Count, Average Fixation Duration, Glance Count, and Average Glance Duration in AOI 12 (Rearward Right Camera Feed) were all predictive of reported False Alarms (appendix I, table 30). Although more Fixations and longer duration Fixations resulted in fewer reported False Alarms, more Glances and longer duration Glances resulted in more reported False Alarms.

3.3.1.3 LOA

There was a main effect of LOA on Fixation Count, Average Fixation Duration, Glance Count, and Average Glance Duration in AOIs 7 (UAS Camera Feed), 8 (UGV Camera Feed), 9 (Forward Right Camera Feed), 11 (Forward Left Camera Feed), 12 (Rearward Right Camera Feed), and 14 (Rearward Left Camera Feed). There were fewer and shorter duration Fixations and Glances in these AOIs during the Manual condition than in either of the RoboLeader conditions.

3.3.1.4 Attention Control

High PAC participants had longer duration glances in AOI 9 and 12 than low PAC participants in all LOAs. Additionally, there was an interaction between PAC and LOA for AOI 14. Participants with high PAC had fewer Fixations and glances, and shorter duration glances, than low PAC participants in the Manual condition, but there was no difference due to PAC for this AOI during the RoboLeader conditions.

3.3.1.5 SpAC

There were interactions between SpAC and LOA for AOIs 8, 9, and 11. AOI 8; high SpAC participants had longer duration Glances during Manual condition than low SPAC. AOI 9; Low SpAC participants made more Fixations and Glances during the RoboLeader conditions than high SpAC participants. AOI 11; Low SpAC participants had shorter duration Fixations in the Manual condition than high SpAC participants. There were main effects of SpAC on fixation and glance behavior in AOIs 11, 12, 13, and 14; low SpAC participants had more Fixations and Glances in AOIs 12, 13, and 14 than high SpAC participants, and had shorter duration Glances in AOI 11 than high SpAC participants.

3.3.1.6 SpAO

High SpAO participants had more Fixations and Glances in AOI 8 than low SpAO participants. Low SpAO participants had longer duration glances in AOIs 9, 11, and 14 than those with high SpAO scores.

3.3.1.7 Gaming Experience

Frequent Action Gamers had more Fixations and Glances in AOIs 7 and 8 than All Other Gamers. Frequent Action Gamers had shorter duration Fixations in AOI 11, and shorter duration Glances in AOI 14, than All Other Gamers.

3.3.1.8 Clicking Behavior

Clicking in AOIs 10, 11, and 12 was predictive of better performance on the Target Detection Task. Frequent Action Gamers clicked in AOI 8 more often than All Other Gamers in Manual and Full Autonomous conditions.

Table 6 shows overall AOI usage, averaged across all participants, for each of the mission automation conditions. For example, Average Dwell Time is the total glance time in that AOI expressed as a percentage of total mission time. This table shows not only how attended that AOI was as compared to the other AOIs in any given mission condition but also how changes in mission automation condition affected how a particular AOI was used. It is important to note that the Manual condition had an additional Vehicle Spacing Task that the Semi- and Fully Autonomous conditions did not, so fixations and glances in AOIs 1 and 4 may be artificially inflated in the Manual condition.

The measure "Clicked in AOI" is a count of participants who clicked within an AOI, with the premise being that if the participant clicked in the AOI once, most likely they continued to use that AOI for the remainder of that mission. Some AOIs had no reason for a participant to click inside that area (no task or buttons), and some AOIs required the participant to click in them either because they were directed to, or because it was central to a main task. Neither of those types of AOIs were analyzed for clicking behavior. The AOIs that were reviewed for clicking behavior were those that could be used (clicked in) to perform a task, but the choice whether or not to utilize that AOI in that manner was up to the participant.

Table 6. Overall area of interest (AOI) usage, by LOA, across all participants.

Area of Interest	Manual						Semi-Autonomous						Full Autonomous					
	Avg Dwell Time[a]	Avg Glance Count	Avg Glance Duration (ms)	Avg Fixation Count	Avg Fixation Duration (ms)	Clicked in AOI[c]	Avg Dwell Time[a]	Avg Glance Count	Avg Glance Duration (ms)	Avg Fixation Count	Avg Fixation Duration (ms)	Clicked in AOI[c]	Avg Dwell Time[a]	Avg Glance Count	Avg Glance Duration (ms)	Avg Fixation Count	Avg Fixation Duration (ms)	Clicked in AOI[c]
1 - AOI Map[b]	37.4%	323	1259.6	1282	295.2	NA	19.0%	248	994.9	825	255.3	NA	18.3%	233	944.8	765	255.5	NA
2 - AOI Message Center	0.2%	4	328.6	6	193.6	NA	0.1%	4	374.1	8	206.6	NA	0.3%	9	379.3	17	183.2	NA
3 - AOI Replan - Cont	0.2%	9	254.7	12	188.7	NA	0.2%	9	293.9	12	203.5	NA	0.3%	12	267.1	17	190.9	NA
4 - AOI Edit Route Dialogue	1.7%	59	323.1	93	198.0	NA	0.3%	11	311.8	18	195.5	NA	0.4%	14	311.7	23	179.8	NA
5 - AOI Start - Undo - Threat	0.4%	14	224.4	18	175.1	NA	0.4%	17	274.5	21	191.4	NA	0.4%	16	245.9	22	189.4	NA
6 - AOI Vehicle List	1.2%	47	279.1	69	189.5	NA	0.5%	18	261.6	26	196.3	NA	0.6%	20	252.9	31	162.4	NA
7 - AOI UAV	1.4%	34	459.1	75	186.2	NA	2.4%	54	500.3	127	194.8	NA	2.4%	51	514.9	125	193.8	NA
8 - AOI UGV	5.4%	100	551.0	248	213.0	43.3%	8.8%	157	651.4	408	230.6	40.0%	8.3%	138	672.3	371	231.1	33.3%
9 - MGV Front Right	4.2%	113	388.5	197	211.3	76.7%	6.3%	160	466.1	317	225.8	80.0%	6.3%	158	451.1	309	218.8	86.7%
10 - MGV Front Center	26.3%	420	660.8	1010	255.0	90.0%	36.0%	550	795.3	1498	270.6	96.7%	35.8%	543	753.3	1462	262.2	93.3%
11 - MGV Front Left	3.5%	106	355.4	174	204.9	66.7%	5.6%	165	406.4	291	216.6	83.3%	5.4%	157	384.1	283	206.7	76.7%
12 - MGV Rear Right	4.6%	131	386.5	234	198.8	63.3%	5.6%	162	419.2	310	202.9	73.3%	5.7%	163	399.8	308	194.9	50.0%
13 - MGV Rear Center	10.9%	292	395.5	509	216.6	100.0%	9.9%	293	415.5	499	226.8	100.0%	10.7%	301	431.4	528	217.8	100.0%
14 - MGV Rear Left	4.1%	129	345.0	219	195.0	60.0%	4.9%	155	381.7	276	200.6	60.0%	4.9%	153	367.8	268	194.9	73.3%

[a] "Average Dwell Time" is the percent of Total Mission time spent as glances within that AOI, across all participants.
[b] Usage data for Manual condition includes a Vehicle Spacing Task which the Semi and Full Autonomous conditions do not.
[c] "Clicked in AOI" is the percentage of participants that clicked within the AOI at least one time in that mission condition.

3.3.2 Usability – Findings From Survey, Include Significant Comments

Participants evaluated the Fully Autonomous condition for perceived usability and overall trust in the system using the Usability and Trust Survey (Chen and Barnes, 2012a). Higher scores indicated the Fully Autonomous condition was easier to use, as well as generated more trust in the participant towards the automation. As such, higher survey scores were expected to correlate with better performance on the Target Detection task, and lower reported FAs. The Usability and Trust Survey has a scoring range of 22–154 points. Participant scores (Min = 108, Max = 144, $M = 124.75$, $SD = 9.45$) indicated that most participants found RoboLeader easy to use and trusted the information provided by the automation.

Usability scores did not correlate with performance on the Target Detection Task or reported number of FAs, nor did they correlate with perceived workload (NASA-TLX scores) or any individual difference factors.

Participants were encouraged to write any comments they wished on the usability survey, and those comments are included in appendix J.

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4.   Discussion

The goals of this study were to determine whether RoboLeader's LOA in managing a convoy improves a commander's ability to maintain 360° security, whether individual differences (SpA, PAC, and Gaming Experience) have differential effects on the commander's ability to maintain security, and whether increasing levels of assistance resulted in reduced workload and improved scanning efficiency. In all mission conditions, the participants' primary task was to identify threats to security while maintaining SA. The level of automated assistance in managing the convoy vehicle spacing and route varied across mission conditions, but all participants were exposed to each LOA.

As per our hypothesis, all participants identified fewer threats in the Manual condition and more threats in the RoboLeader conditions. Participants with low SpAO improved their performance to a level similar to those with high SpAO, which is consistent with previous findings (Chen and Terrence, 2009) that automation can bring the performance of persons with low SpA to nearly the same level as those with high SpA. Participants with high SpAO benefited the most from a moderate amount of automated assistance in the Semi-Autonomous condition, with their performance dropping off in the Fully Autonomous condition to the same as those with low SpAO. This indicates that, in the present scenario, there is an optimal amount of automation for a multitasking environment, beyond which the automation does not improve performance or can become detrimental to task performance for some users, possibly leading to automation-induced complacency (Parasuraman et al., 1993).

FAs were significantly higher in the Semi-Autonomous condition than either the Manual or the Fully Autonomous conditions for all participants. It is interesting that, while the Semi-Autonomous condition seemed to be the best balance for performance and automation for several measures, it was the worst condition for FAs. While the participants had more time to detect targets in the Semi-Autonomous condition than they had in the Manual condition, their workload was still higher than in the Fully Autonomous condition, creating an opportunity for overtrust or complacency that resulted in increased FAs (Yeh and Wickens, 2000).

Participants with high SpAO maintained higher SA across Mission Conditions than those with lower SpAO. While RoboLeader helped those with low SpAO maintain higher SA in both Semi- and Fully Autonomous conditions, it did not appear to benefit those with high SpAO. These results are consistent with previous findings (Chen and Terrence, 2009) that automation can bring the performance of person's with low SpA to nearly the same level as those with high SpA.

Overall, the results show that RoboLeader was effective in improving participants' target detection performance and SA while decreasing perceived workload, regardless of individual differences. However, participants with lower SpA benefited the most from RoboLeader's assistance, often bringing their performance near the same as those with higher SpA.

LOA affected perceived workload, with each successive increase in autonomy showing a decrease in perceived workload as reported using the NASA-TLX. However, physiological eyetracking data did not fully support the finding of the NASA-TLX; Blink Rate and Fixation Count indicated the RoboLeader conditions were nearly equivalent on workload, while the Manual condition induced the highest level of workload. Nonetheless, as workload decreased, so did the average length of saccades, indicating more efficient scanning patterns in the Semi-Autonomous condition than in the Manual condition. Previous studies have differed on perceived workload as well; RoboLeader's presence did not appear to affect perceived workload in Chen and Barnes (2012a), however, in Chen and Barnes (2012b) participants reported lower workload when assisted by RoboLeader. It is possible that the difference in reported workload between the RoboLeader conditions is actually a difference in participant engagement (i.e., boredom).

Average Pupil Diameter was largest in the Manual condition—indicating it was most taxing and decreased for each successive increase in automation, which is evidence that each additional LOA made the trial less difficult or interesting (Van Orden et al., 2000, 2001; Iqbal et al., 2004; Kang et al., 2009), and this finding agrees with the reported NASA-TLX scores. However, pupil dilation depended on PAC individual differences. Participants' measured Average Pupil Diameter was divided along Attentional Control scores; those with low PAC had consistent Pupil Diameter regardless of LOA, while Pupil Diameter of the high PAC participants decreased with each successive LOA, as well as being considerably larger than the low PAC groups' Pupil Diameters in all conditions. Low PAC participants had higher Fixation Counts across LOA than high PAC participants, which when considered with the Pupil Diameter findings would suggest that low PAC participants were working at their highest capacity, and as such, could not keep up

with the task demands, resulting in a leveling off of Pupil Diameter changes (Peavler, 1974). However, Blink Rate, Fixation Count, and Saccadic Amplitude were not significantly different between the two RoboLeader conditions, whereas the TLX scores suggest at least a perceived difference among the conditions. The individual differences in PAC suggest that high PAC participants spent the least effort on the highest automation level without a concomitant increase in performance compared to the low PAC participants. More telling, as mentioned above, individuals with the highest scores on SpAO showed a decreased hit rate for targeting for the highest LOA compared to the mid-level, implying too much automaton may be detrimental for highly skilled operators (see Parasuraman et al., 2009).

4.1   AOI Usage

A secondary goal of this study was to evaluate the utility of the OCU in general, and various camera feeds specifically, in performing the Target Detection Task and maintaining SA. Differential effects of Spatial Ability, PAC, and Gaming Experience on utility were also examined.

The tendency for an operator to center their vision on a central area of a display is well documented, and the farther from the center an object or area is, the less likely operators will attend to it (Tatler, 2007). However, in order for the participant to perform well in this experiment, they were required to visually monitor the periphery of the display. How this is being done and who is doing it is of great interest to display designers, as well as those who would train potential operators.

AOI 2 was the incoming message center, where the participant would receive messages either identifying a threat to avoid or investigate. When workload was high, participants did not rely on AOI 2 for this information, instead they relied on using the color-coded information that appeared on their interactive map to determine what response was required of them. This appears to be an example of successful dual notification systems; when resources were limited, the participants were still able to receive and correctly interpret the meaning of the message. This experiment had only two potential incoming messages, more complex or diverse messages may result in interpretation failure.

AOI 7 was the UAS camera feed in the upper left corner of the OCU display, and it was expected that participants who maintained high SA would monitor this camera feed for information. However, overall glance behavior in this AOI did not predict SA. Frequent Action Gamers and participants with high SpAO scored higher on SA measures than other participants, but of the two, only the Frequent Action Gamers actively monitored this AOI across all automation levels. This implies that while this information could be useful for maintaining SA, practice and experience are needed to teach operators how to use this information.

AOI 8 was the UGV camera feed, located upper mid-screen on the left side of the display. Views in this camera feed gave the participant an advanced view of their route; approximately 50 meters ahead of the manned vehicle, and the participant could mark targets using this camera feed. It was expected that participants who scored well on the Target Detection Task, and those that had the fewest FAs, would utilize this AOI. Participants who had the longest Average Fixations in this AOI did perform better on the Target Detection Task, but only in the Fully Autonomous condition. There were fewer Fixations and Glances in AOI 8 in the Manual condition than in the RoboLeader conditions, across all participants, indicating that when workload increased this AOI was not utilized as often. Participants who were not Frequent Action Gamers were less likely to use this AOI to mark targets, regardless of automation level.

AOIs 9, 10, and 11 comprised the MGV forward camera feed, and it was expected that this feed would be used for maintaining SA and conducting the Target Detection Task. Overall Fixation and Glance behavior in AOIs 9, 10, and 11 were not predictive of performance in the Target Detection Task or of reported FAs. Frequent Action Gamers had significantly shorter duration Fixations and Glances in AOIs 10, and 11, while low SpAC and low SpAO participants had longer and more frequent glances in AOIs 9, 10, and 11. This implies that those participants that have developed more advanced scanning strategies relied on information from these AOIs less than other participants did, while participants with poor SpA relied on the forward camera feeds more than participants with high SpA.

AOIs 12, 13, and 14 comprised the MGV rearward camera feed, and it was expected that this feed would be used for maintaining SA and conduction the Target Detection Task. Overall Fixation and Glance behavior in AOIs 12, 13, and 14 were not predictive of performance in the Target Detection Task. Overall Fixation and Glance behavior in AOI 12 were predictive of reported FAs in the Manual condition. Frequent Action Gamers and high SpAO participants had significantly shorter duration Fixations and Glances in AOI 14, while low SpAC participants had more frequent Fixations and Glances in AOIs 12, 13, and 14. Participants with more developed scanning strategies optimized their glance behavior in these AOIs, while participants with poorer SpA attempted to monitor this feed (as indicated by the high number of fixations), however, they did not necessarily gain better information from their attempts (as indicated by the higher number of FAs). Most participants did incorporate AOIs 12, 13, and 14 into their Target Detection strategy, however, usage decreased as the LOA decreased.

5. Conclusions

In the current study, we investigated whether increasing RoboLeader's LOA improved an operator's ability to maintain 360° security and SA, reduced workload levels and improved scan efficiency, as well as the effect of individual differences on performance across LOAs. Overall,

increasing LOA did improve performance in the Target Detection Task and result in lower reported workload; however, there appear to be differential effects due to individual differences that would suggest an optimal level of assistance exists. We see a performance drop on the target detection task for the high SpAO group in the Full Autonomous condition. Although the low SpAO group improves slightly with each increasing LOA, the loss in performance of the high SpAO group is greater than the gain of the low SpAO in the Full Autonomous condition. Thus, overall performance on the target detection task depended in individual differences in spatial ability as well as LOA. Some of the eye-tracking behavior data suggest this could be due to skilled operators' disengagement at the highest LOA.

Increasing LOA did reduce reported workload, with each increasing LOA significantly reducing workload. However, eye behavior data indicates there were differential effects due to PAC, with participants with high PAC able to benefit from the increasing LOA while those with low PAC struggling regardless of LOA.

Usability analysis of the OCU demonstrated that the participants with high SpA and Frequent Action Gamers were better able to utilize the entire display than their counterparts, and results indicate this led to improved performance and SA scores. Increased LOA also resulted in better display utilization.

Future research should investigate how dependent this seeming "optimal" level of assistance is on task number and type, as well as explore OCU designs which could be equally effective regardless of the operators' scanning expertise and/or skill. Personnel testing and training should also be explored, so that operators with low SpA and PAC can perform at similar levels to those with high SpA and PAC. In addition, automation itself seems to be an equalizer for low spatial abilities as well as low PAC, with the caveat that high levels can be detrimental to more highly skilled individuals because the automated tasks fail to capture their full attention. The literature on adaptive automation argues that automation can be modulated to optimally engage the operator depending on task difficulty; these data suggest that adaptation should be dependent on the operator's skill level as well (Chen et al., 2011; Parasuraman et al., 2009)

6. References

Adams, E. *Fundamentals of Game Design*. New Riders: Berkeley, CA, 2010.

Adams, J. A. Multiple Robot/Single Human Interaction: Effects on Perceived Workload. *Behaviour & Information Technology* **2009**, *28* (2), 183–198.

Altmann, E. M., Trafton, J. G. Task interruption: Resumption Lag and the Role of Cues. In *Proceedings of the 26th Annual Conference of the Cognitive Science Society*, 2004; pp 42–47.

Astle, D. E., Scerif, G. Using Developmental Cognitive Neuroscience to Study Behavioral and Attentional Control. *Developmental Psychobiology* **2009**, *51* (2), 107–118.

Barber, D.; Davis, L.; Nicholson, D.; Finkelstein, N; Chen, J. Y. C. The Mixed Initiative Experimental (MIX) Testbed for Human Robot Interactions With Varied Levels of Automation. In *Proceedings of the 26th Army Science Conference* (Orlando, FL, 1–4 December 2008). ASC '08. U.S. Dept. of Army, Washington, DC.

Chen, J. Y. C.; Barnes, M. J. Supervisory Control of Multiple Robots: Effects of Imperfect Automation and Individual Differences. *Human Factors: The Journal of the Human Factors and Ergonomics Society* **2012a**, *54* (2), 157–174.

Chen, J. Y. C.; Barnes, M. J. Supervisory Control of Multiple Robots in Dynamic Tasking Environments. *Ergonomics* **2012b**, *55*, 1043–1058.

Chen, J. Y.; Barnes, M. J.; Harper-Sciarini, M. (2011). Supervisory Control of Multiple Robots: Human-Performance Issues and User-Interface Design. *Systems, Man, and Cybernetics, Part C: Applications and Reviews, IEEE Transactions on* **2011**, *41* (4), 435–454.

Chen, J. Y. C.; Durlach, P. J.; Sloan, J. A.; Bowens, L. D. Human Robot Interaction in the Context of Simulated Route Reconnaissance Missions. *Military Psychology* **2008**, *20*, 135–149.

Chen, J. Y. C.; Joyner, C. T. Concurrent Performance of Gunner's and Robotic Operator's Tasks in a Multi-Tasking Environment. *Military Psychology* **2009**, *21* (1), 98–113.

Chen, J. Y. C.; Terrence, P. I. Effects of Imperfect Automation and Individual Differences on Concurrent Performance of Military and Robotics Tasks in a Simulated Multitasking Environment. *Ergonomics* **2009**, *52* (8), 907–920.

Chisholm, S. L.; Caird, J. K.; Lockhart, J. (2008). The Effects of Practice With MP3 Players on Driving Performance. *Accident Analysis & Prevention* **2008**, *40* (2), 704–713.

Cummings, M. L. The Need for Command and Control Instant Message Adaptive Interfaces: Lessons Learned From Tactical Tomahawk Human-in-the-Loop Simulations. *Cyber Psychology & Behavior* **2004**, *7*(6), 653–661.

Cummings, M. L.; Clare, A.; Hart, C. The Role of Human-Automation Consensus in Multiple Unmanned Vehicle Scheduling. *Human Factors: The Journal of the Human Factors and Ergonomics Society* **2010**, *52* (1), 17–27.

Derryberry, D.; Reed, M. A. Anxiety-Related Attentional Biases and Their Regulation by Attentional Control. *Journal of Abnormal Psychology* **2002**, *111* (2), 225–236.

Ehmke, C.; Wilson, S. Identifying Web Usability Problems From Eye-Tracking Data. In *Proceedings of the 21st British HCI Group Annual Conference on People and Computers: HCI... but not as we know it-Volume 1,* British Computer Society, September 2007); 119–128.

Elliott, L., et al. *Impact of a 360° Advanced Sensor System and Crew Configuration on User Performance*; ARL Technical Report, (in press).

Ekstrom, R. B.; French, J. W.; Harman, H. H. *Kit of Factor-Referenced Cognitive Tests*; Educational Testing Service: Princeton, NJ, 1976.

Endsley, M. R. Toward a Theory of Situation Awareness in Dynamic Systems. *Human Factors: The Journal of the Human Factors and Ergonomics Society* **1995**, *37* (1), 32–64.

Endsley, M. R. Level of Automation Effects on Performance, Situation Awareness and Workload in a Dynamic Control Task. *Ergonomics* **1999**, *42* (3), 462–492.

Fehd, H. M.; Seiffert, A. E. Looking at the Center of the Targets Helps Multiple Object Tracking. *Journal of Vision* **2010**, *10* (4).

Friedman, A.; Liebelt, L. S. On the Time Course of Viewing Pictures With a View Towards Remembering. *Eye Movements: Cognition and Visual Perception* **1981**, 137–155.

Goldberg, J. H.; Kotval, X. P. Computer Interface Evaluation Using Eye Movements: Methods and Constructs. *International Journal of Industrial Ergonomics* **1999**, *24* (6), 631–645.

Green, C. S.; Bavelier, D. Action Video Game Modifies Visual Selective Attention. *Nature* **2003**, 423, 534–537.

Green, C. S.; Bavelier, D. Enumeration Versus Multiple Object Tracking: The Case of Action Video Game Players. *Cognition* **2006**, *101* (1), 217.

Gugerty, L; Brooks, J. Reference-Frame Misalignment and Cardinal Direction Judgments: Group Differences and Strategies. *Journal of Experimental Psychology: Applied* **2004**, *10* (2), 75–88.

Hart, S.; Staveland, L. Development of NASA TLX (Task Load Index): Results of Empirical and Theoretical Research. In *Human Mental Workload*; Hancock, P., Meshkati, N., Eds.; Elsevier: Amsterdam, 1988; 139–183.

Hauland, G. Measuring Individual and Team Situation Awareness During Planning Tasks in Training of en route Air Traffic Control. *The International Journal of Aviation Psychology* **2008**, *18* (3), 290–304.

Holmqvist, K.; Nyström, M.; Andersson, R.; Dewhurst, R.; Jarodzka, H.; Van de Weijer, J. *Eye Tracking: A Comprehensive Guide to Methods and Measures*; OUP Oxford, 2011.

Iqbal, S. T.; Zheng, X. S.; Bailey, B. P. Task-Evoked Pupillary Response to Mental Workload in Human-Computer Interaction. In *CHI'04 Extended Abstracts on Human Factors in Computing Systems*, 2004, 1477–1480.

Jacob, R. J.; Karn, K. S. Eye Tracking in Human-Computer Interaction and Usability Research: Ready to Deliver the Promises. *Mind* **2003**, *2* (3), 4.

Jian, J.; Bisantz, A. M.; Drury, C. G. Foundations for an Empirically Determined Scale of Trust in Automated Systems. *International Journal of Cognitive Ergonomics* **2000**, *4* (1), 53–71.

Kang, M. J.; Hsu, M.; Krajbich, I. M.; Loewenstein, G.; McClure, S. M.; Wang, J. T. Y.; Camerer, C. F. The Wick in the Candle of Learning: Epistemic Curiosity Activates Reward Circuitry and Enhances Memory. *Psychological Science* **2009**, *20* (8), 963–973.

Kasarskis, P.; Stehwien, J.; Hickox, J.; Aretz, A.; Wickens, C. Comparison of Expert and Novice Scan Behaviors During VFR Flight. In *Proceedings of the 11th International Symposium on Aviation Psychology*, 2001.

Lathan, C.; Tracey, M. The Effects of Operator Spatial Perception and Sensory Feedback on Human-Robot Teleoperation Performance. *Presence* **2002**, *11*, 368–377.

Loftus, G. R.; Mackworth, N. H. Cognitive Determinants of Fixation Location During Picture Viewing. *Journal of Experimental Psychology: Human Perception and Performance* **1978**, *4* (4), 565.

Manzey, D.; Reichenbach, J.; Onnasch, L. Performance Consequences of Automated Aids in Supervisory Control: The Impact of Function Allocation. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, 2008, *52* (4), pp 297–301.

May, J. G.; Kennedy, R. S.; Williams, M. C.; Dunlap, W. P.; Brannan, J. R. Eye Movement Indices of Mental Workload. *Acta Psychological* **1990**, *75* (1), 75.

McKinley, R. A.; McIntire, L. K.; Funke, M. A. Operator Selection for Unmanned Aerial Systems: Comparing Video Game Players and Pilots. *Aviation, Space, and Environmental Medicine* **2011**, *82* (6), 635–642.

Monsell, S. Task switching. *Trends in Cognitive Sciences* **2003**, *7* (3), 134–140.

Ottati, W. L.; Hickox, J. C.; Richter, J. Eye Scan Patterns of Experienced and Novice Pilots During Visual Flight Rules (VFR) Navigation. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, 1999, *43* (1), 1999; pp 66–70.

Parasuraman, R.; Cosenzo, K. A.; De Visser, E. Adaptive Automation for Human Supervision of Multiple Uninhabited Vehicles: Effects on Change Detection, Situation Awareness, and Mental Workload. *Military Psychology* **2009**, *21* (2), 270–297.

Parasuraman, R.; Molloy, R.; Singh, I. L. Performance Consequences of Automation-Induced Complacency. *The International Journal of Aviation Psychology* **1993**, *3* (1), 1–23.

Parasuraman, R.; Riley, V. Humans and Automation: Use, Misuse, Disuse, Abuse. *Human Factors: The Journal of the Human Factors and Ergonomics Society* **1997**, *39* (2), 230–253.

Parasuraman, R.; Sheridan, T. B.; Wickens, C. D. A Model for Types and Levels of Human Interaction With Automation. *Systems, Man and Cybernetics, Part A: Systems and Humans, IEEE Transactions on* **2000**, *30* (3), 286–297.

Peavler, W. S. Pupil Size, Information Overload, and Performance Differences. *Psychophysiology* **1974**, *11* (5), 559–566.

Recarte, M. A.; Nunes, L. M. Mental Workload While Driving: Effects on Visual Search, Discrimination, and Decision Making. *Journal of Experimental Psychology: Applied; Journal of Experimental Psychology: Applied* **2003**, *9* (2), 119.

Reichenbach, J.; Onnasch, L.; Manzey, D. Misuse of Automation: The Impact of System Experience on Complacency and Automation Bias in Interaction With Automated Aids. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, 2010, *54* (4), pp 374–378.

Reingold, E. M.; Charness, N.; Pomplun, M.; Stampe, D. M. Visual Span in Expert Chess Players: Evidence From Eye Movements. *Psychological Science* **2001**, *12* (1), 48–55.

Rubinstein, J.; Meyer, D.; Evans, J. Executive Control of Cognitive Processes in Task Switching. *Journal of Experimental Psychology: Human Perception and Performance* **2001**, *27*, 763–797.

Ruff, H. A.; Narayanan, S.; Draper, M. H. Human Interaction With Levels of Automation and Decision-Aid Fidelity in the Supervisory Control of Multiple Simulated Unmanned Air Vehicles. *Presence: Teleoperators & Virtual Environments* **2002**, *11* (4), 335–351.

Shimojo, S.; Simion, C.; Shimojo, E.; & Scheier, C. Gaze Bias Both Reflects and Influences Preference. *Nature Neuroscience* **2003**, *6* (12), 1317–1322.

SMI. iViewX System Manual, Version 2.8, 2011.

SMI. RED Eye Tracker Technical Specs. Available: http://www.smivision.com/fileadmin /user_upload/downloads/product_flyer/prod_smi_red_techspecs.pdf (accessed March 2013).

Snyder, M.; Qu, Z.; Chen, J. Y. C.; Barnes, M. RoboLeader for Reconnaissance by a Team of Robotic Vehicles. In *Proceedings of the International Symposium on Collaborative Technologies and Systems* CTS '10. IEEE, (Chicago, 17–21 May 2010). New York, 522–530.

Squire, P. N.; Parasuraman, R. R. Effects of Automation and Task Load on Task Switching During Human Supervision of Multiple Semi-Autonomous Robots in a Dynamic Environment. *Ergonomics* **2010**, *53* (8), 951–961. doi:10.1080/00140139.2010.489969.

Squire, P.; Trafton, G.; Parasuraman, R. Human Control of Multiple Unmanned Vehicles: Effects of Interface Type on Execution and Task Switching Times. In *Proceedings of the 1st ACM SIGCHI/SIGART Conference on Human-Robot Interaction*, 2006; pp 26–32.

Stern, J. A.; Boyer, D.; Schroeder, D. Blink Rate: A Possible Measure of Fatigue. *Human Factors: The Journal of the Human Factors and Ergonomics Society* **1994**, *36* (2), 285–297.

Tabachnick, B. G.; Fidell, L. S. *Using Multivariate Statistics*; Pearson Education, Inc.: Boston, MA, 2007.

Tatler, B. W. The Central Fixation Bias in Scene Viewing: Selecting an Optimal Viewing Position Independently of Motor Biases and Image Feature Distributions. *Journal of Vision* **2007**, *7* (14).

Tatler, B. W.; Baddeley, R. J.; Vincent, B. T. The Long and the Short of it: Spatial Statistics at Fixation Vary With Saccade Amplitude and Task. *Vision Research* **2006**, *46* (12), 1857–1862.

Tatler, B. W.; Gilchrist, I. D.; Land, M. F. Visual Memory for Objects in Natural Scenes: From Fixations to Object Files. *The Quarterly Journal of Experimental Psychology Section A* **2005**, *58* (5), 931–960.

Thomas, L. C.; Wickens, C. D. Eye-Tracking and Individual Differences in Off-Normal Event Detection When Flying With a Synthetic Vision System Display. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, 2004, *48* (1); 223–227.

Van Orden, K. F.; Jung, T. P.; Makeig, S. Combined Eye Activity Measures Accurately Estimate Changes in Sustained Visual Task Performance. *Biological Psychology* **2000**, *52* (3), 221–240.

Van Orden, K. F.; Limbert, W.; Makeig, S.; Jung, T. P. Eye activity Correlates of Workload During a Visuospatial Memory Task. *Human Factors: The Journal of the Human Factors and Ergonomics Society* **2001**, *43* (1), 111–121.

Wang, H.; Lewis, M.; Velagapudi, P.; Scerri, P.; Sycara, K. How Search and its Subtasks Scale in N Robots. *Proceedings of the 4th ACM/IEEE International Conference on Human-Robot Interaction*; Association for Computing Machinery: New York, 2009; pp 141–147.

Wang, J.; Wang, H.; Lewis, M. Assessing Cooperation in Human Control of Heterogeneous Robots. *Proceedings of the 3rd ACM/IEEE International Conference on Human-Robot Interaction*; Association for Computing Machinery: New York, 2008; pp 9–15.

Warm, J. S.; Dember, W. N.; Hancock, P. A. Vigilance and Workload in Automated Systems. In *Automation and Human Performance: Theory and Applications*; Parasuraman, R., Mouloua, M., Eds.; Erlbaum: Mahwah, NJ, 1996; 183–200.

Warm, J. S.; Parasuraman, R.; Matthews, G. Vigilance Requires Hard Mental Work and is Stressful. *Human Factors: The Journal of the Human Factors and Ergonomics Society* **2008**, *50* (3), 433–441.

Wickens, C. D.; Lee, J.; Liu, Y. D.; Gordon-Becker, S. *Introduction to Human Factors Engineering*; Prentiss-Hall, Inc.: Upper Saddle River, NJ, 2003.

Williams, A. M.; Davids, K.; Burwitz, L.; Williams, J. G. Visual Search Strategies in Experienced and Inexperienced Soccer Players. *Research Quarterly for Exercise and Sport*, *65* (2), 1994, 127.

Yeh, M.; Wickens, C. D. Effects of Cue Reliability, Realism, and Interactivity on Biases of Attention and Trust in Augmented Reality. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, *44* (5), 2000; pp 511–514.

Zelinsky, G. J.; Sheinberg, D. L. Eye Movements During Parallel–Serial Visual Search. *Journal of Experimental Psychology: Human Perception and Performance* **1997**, *23* (1), 244.

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Appendix A. Demographics Questionnaire

Demographic Questionnaire

Participant # _____   Age _____   Major _____   Date _____   Gender ____

1. What is the <u>highest</u> level of education you have had?

    Less than 4 yrs of college _____   Completed 4 yrs of college _____   Other _____

2. When did you use computers in your education? (*Circle all that apply*)

    Grade School   Jr. High   High School
    Technical School   College   Did Not Use

3. Where do you currently use a computer? (*Circle all that apply*)

    Home   Work   Library   Other_____   Do Not Use

4. For each of the following questions, <u>circle</u> the response that best describes you.

    How often do you:
    Use a mouse?   Daily, Weekly, Monthly, Once every few months, Rarely, Never
    Use a joystick?   Daily, Weekly, Monthly, Once every few months, Rarely, Never
    Use a touch screen?   Daily, Weekly, Monthly, Once every few months, Rarely, Never
    Use icon-based programs/software?
                                Daily, Weekly, Monthly, Once every few months, Rarely, Never
    Use programs/software with pull-down menus?
                                Daily, Weekly, Monthly, Once every few months, Rarely, Never
    Use graphics/drawing features in software packages?
                                Daily, Weekly, Monthly, Once every few months, Rarely, Never
    Use E-mail?   Daily, Weekly, Monthly, Once every few months, Rarely, Never
    Operate a radio controlled vehicle (car, boat, or plane)?
                                Daily, Weekly, Monthly, Once every few months, Rarely, Never
    Play computer/video games?
                                Daily, Weekly, Monthly, Once every few months, Rarely, Never

5. Which type(s) of computer/video games do you most often play if you play at least once every few months?

6. Which of the following best describes your expertise with computer? (check √ one)
    _____ Novice
    _____ Good with one type of software package (such as word processing or slides)
    _____ Good with several software packages
    _____ Can program in one language and use several software packages
    _____ Can program in several languages and use several software packages

7. Are you in your good/ comfortable state of health physically?   YES   NO
    If NO, please briefly explain:

8. How many hours of sleep did you get last night? _____ hours

9. Do you have normal color vision?   YES   NO

10. Do you have prior military service? YES   NO   If Yes, how long _____

Appendix B. Attentional Control Survey

Attentional Control Survey   **Participant #_____**   **Date _____**

For each of the following questions, <u>circle</u> the response that best describes you.

It is very hard for me to concentrate on a difficult task when there are noises around.
<div align="right">Almost never, Sometimes, Often, Always</div>

When I need to concentrate and solve a problem, I have trouble focusing my attention.
<div align="right">Almost never, Sometimes, Often, Always</div>

When I am working hard on something, I still get distracted by events around me.
<div align="right">Almost never, Sometimes, Often, Always</div>

My concentration is good even if there is music in the room around me.
<div align="right">Almost never, Sometimes, Often, Always</div>

When concentrating, I can focus my attention so that I become unaware of what's going on in the room around me.
<div align="right">Almost never, Sometimes, Often, Always</div>

When I am reading or studying, I am easily distracted if there are people talking in the same room.
<div align="right">Almost never, Sometimes, Often, Always</div>

When trying to focus my attention on something, I have difficulty blocking out distracting thoughts.
<div align="right">Almost never, Sometimes, Often, Always</div>

I have a hard time concentrating when I'm excited about something.
<div align="right">Almost never, Sometimes, Often, Always</div>

When concentrating, I ignore feelings of hunger or thirst.   Almost never, Sometimes, Often, Always

I can quickly switch from one task to another.   Almost never, Sometimes, Often, Always

It takes me a while to get really involved in a new task.   Almost never, Sometimes, Often, Always

It is difficult for me to coordinate my attention between the listening and writing required when taking notes during lectures.   Almost never, Sometimes, Often, Always

I can become interested in a new topic very quickly when I need to.
<div align="right">Almost never, Sometimes, Often, Always</div>

It is easy for me to read or write while I'm also talking on the phone.
<div align="right">Almost never, Sometimes, Often, Always</div>

I have trouble carrying on two conversations at once.   Almost never, Sometimes, Often, Always

I have a hard time coming up with new ideas quickly.   Almost never, Sometimes, Often, Always

After being interrupted or distracted, I can easily shift my attention back to what I was doing before.
<div align="right">Almost never, Sometimes, Often, Always</div>

When a distracting thought comes to mind, it is easy for me to shift my attention away from it.
<div align="right">Almost never, Sometimes, Often, Always</div>

It is easy for me to alternate between two different tasks.   Almost never, Sometimes, Often, Always

It is hard for me to break from one way of thinking about something and look at it from another point of view.
<div align="right">Almost never, Sometimes, Often, Always</div>

Appendix C. Cube Comparison Test

This appendix appears in its original form, without editorial change.

CUBE COMPARISONS TEST -- S-2 (Rev.)

Wooden blocks such as children play with are often cubical with a different letter, number, or symbol on each of the six faces (top, bottom, four sides). Each problem in this test consists of drawings of pairs of cubes or blocks of this kind. Remember, there is a different design, number, or letter on each face of a given cube or block. Compare the two cubes in each pair below.


S ☐   D ▬   S ▬   D ☐
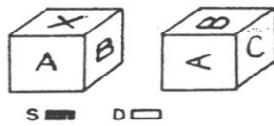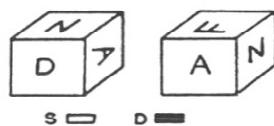
The first pair is marked D because they must be drawings of <u>different</u> cubes. If the left cube is turned so that the A is upright and facing you, the N would be to the left of the A and hidden, not to the right of the A as is shown on the right hand member of the pair. Thus, the drawings must be of different cubes.

The second pair is marked S because they could be drawings of the same cube. That is, if the A is turned on its side the X becomes hidden, the B is now on top, and the C (which was hidden) now appears. Thus the two drawings could be of the same cube.

<u>Note</u>: No letters, numbers, or symbols appear on more than one face of a given cube. Except for that, <u>any</u> letter, number or symbol can be on the hidden faces of a cube.

Work the three examples below.

S ☐ D ☐   S ☐ D ☐   S ☐ D ☐
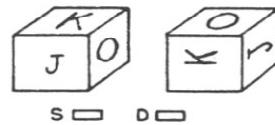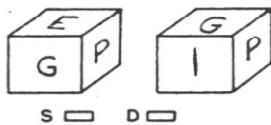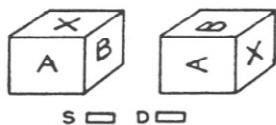
The first pair immediately above should be marked D because the X cannot be at the peak of the A on the left hand drawing and at the base of the A on the right hand drawing. The second pair is "different" because P has its side next to G on the left hand cube but its top next to G on the right hand cube. The blocks in the third pair are the same, the J and K are just turned on their side, moving the O to the top.

Your score on this test will be the number marked correctly minus the number marked incorrectly. Therefore, it will <u>not</u> be to your advantage to guess unless you have some idea which choice is correct. Work as quickly as you can without sacrificing accuracy.

You will have <u>3 minutes</u> for each of the two parts of this test. Each part has one page. When you have finished Part 1, STOP.

DO NOT TURN THE PAGE UNTIL YOU ARE ASKED TO DO SO.

Part 1 (3 minutes)

1.

S ▭   D ▭

2.

S ▭   D ▭

3.

S ▭   D ▭

4.

S ▭   D ▭

5.

S ▭   D ▭

6.

S ▭   D ▭

7.

S ▭   D ▭

8.

S ▭   D ▭

9.

S ▭   D ▭

10.

S ▭   D ▭

11.

S ▭   D ▭

12.

S ▭   D ▭

13.

S ▭   D ▭

14.

S ▭   D ▭

15.

S ▭   D ▭

16.

S ▭   D ▭

17.

S ▭   D ▭

18.

S ▭   D ▭

19.

S ▭   D ▭

20.

S ▭   D ▭

21.
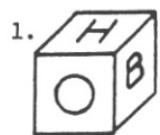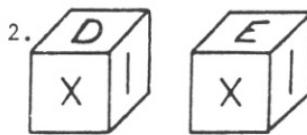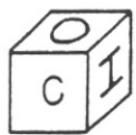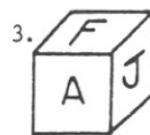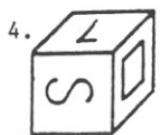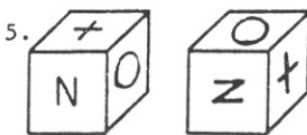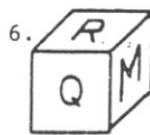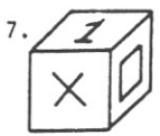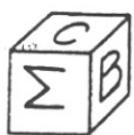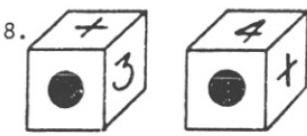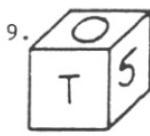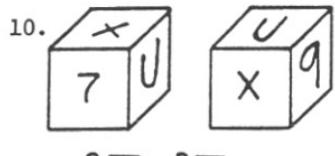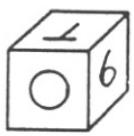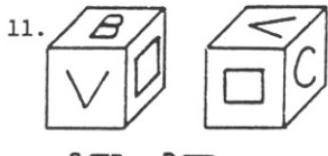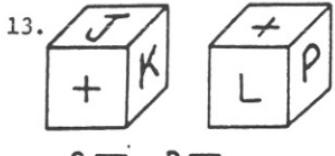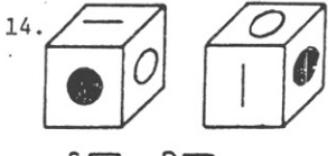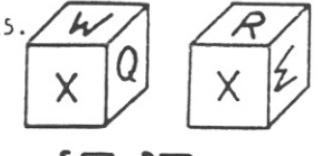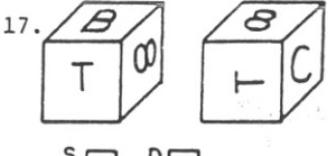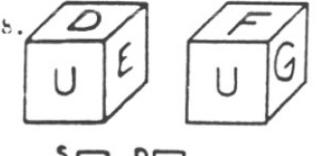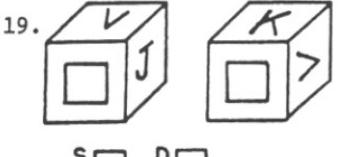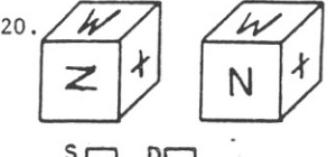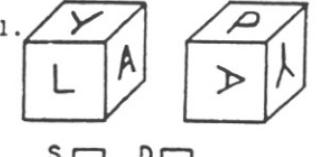
S ▭   D ▭

DO NOT GO ON TO THE NEXT PAGE UNTIL ASKED TO DO SO.   STOP.

45

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Appendix D. Spatial Orientation Test

This appendix appears in its original form, without editorial change.

The Spatial Orientation Test, modeled after the cardinal direction test developed by Gugerty and his colleagues (Gugerty & Brooks, 2004), is a computerized test consisting of a brief training segment and 32 test questions. The program automatically captures both accuracy and response time. Participants are shown the following image:
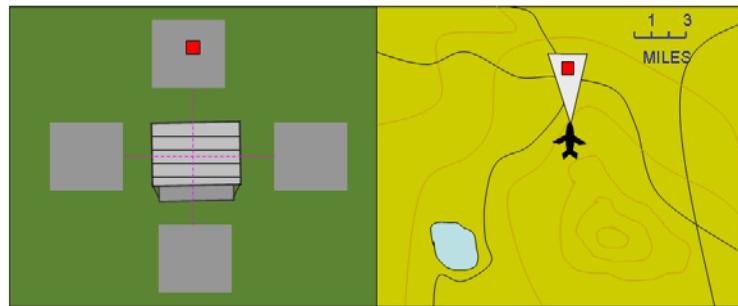
The right side image is of a map showing a plane flying. The left side of the display is the pilot's view (from the cockpit of the plane) of several parking lots surrounding a building. The participants' task is to use the right side of the display to learn in which direction the plane is flying. They then use this information to identify which parking lot (north, south, east, or west) in the left side image has the dot. In the example shown above, the plane is heading north, and so the dot appears in the north parking lot. In the example shown below, the plane is heading south, and so the dot appears in the east parking lot.
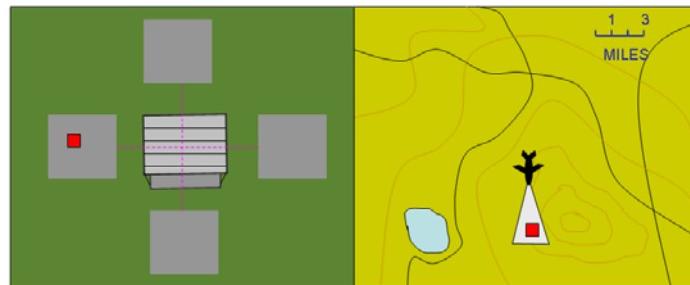
Participants are shown 32 of these images in succession; each time the direction the plane is flying and the location of the dot are randomized. Participants answer by clicking on one of four buttons (North, South, East, or West). This test is self-paced; the participant may take as long as they wish to answer, and when they answer one question the next question automatically appears. No questions can be skipped, and the order of images is randomized among participants.

Appendix E. NASA-TLX Questionnaire

This appendix appears in its original form, without editorial change.

NASA TLX Workload Assessment

Instructions: Ratings Scales

We are interested in the "workload" you experienced during this scenario. Workload is something experienced individually by each person. One way to find out about workload is to ask people to describe what they experienced. Workload may be caused by many different factors and we would like you to evaluate them individually. The set of six workload rating factors was developed for you to use in evaluating your experiences during different tasks. Please read them. If you have a question about any of the scales in the table, please ask about it. It is extremely important that they be clear to you.

Definitions

Title	Endpoints	Descriptions
MENTAL DEMAND	Low / High	How much mental and perceptual activity was required (that is, thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?
PHYSICAL DEMAND	Low / High	How much physical activity was required (that is, pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?
TEMPORAL DEMAND	Low / High	How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?
PERFORMANCE	Poor / Good	How successful do you think you were in accomplishing the goals of the task? How satisfied were you with your performance in accomplishing these goals?
EFFORT	Low / High	How hard did you have to work (mentally and physically) to accomplish your level of performance?
FRUSTRATION LEVEL	Low / High	How insecure, discouraged, irritated, stressed, and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?

We want you to evaluate workload. Rate the workload on each factor on a scale. Each scale has two end descriptions, and 20 slots (hash marks) between the end descriptions. Place an "x" in the slot (between the hash marks) that you feel most accurately reflects your workload.

After you have finished the entire series, we will be able to use the pattern of your choices to create a weighted combination of ratings into a summary workload score.

We ask you to evaluate your workload for this scenario. This includes all the duties involved in your job (e.g., detecting targets and using display).

Participant ID: _____

TLX Workload Scale

Please rate your workload by putting a mark on each of the six scales at the point which matches your experience.

Mental Demand

Low   High

Physical Demand

Low   High

Temporal Demand

Low   High

Performance

Good   Poor

Effort

Low   High

Frustration

Low   High

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Appendix F. Usability and Trust Survey

Usability & Trust Survey   **Comments**

1.   **I found the camera feeds of UAS, UVG and MGV to be helpful during route modification.**
     Strongly DISAGREE |---|---|---|---|---|---| Strongly AGREE   N/A
                           1   2   3   4   5   6   7

2.   **I made use of the RoboLeader's recommendations.**
     Strongly DISAGREE |---|---|---|---|---|---| Strongly AGREE   N/A
                           1   2   3   4   5   6   7

3.   **I sometimes felt 'lost' using the RoboLeader display.**
     Strongly DISAGREE |---|---|---|---|---|---| Strongly AGREE   N/A
                           1   2   3   4   5   6   7

4.   **The RoboLeader display was intuitive and made it easy to determine how to edit routes.**
     Strongly DISAGREE |---|---|---|---|---|---| Strongly AGREE   N/A
                           1   2   3   4   5   6   7

5.   **I do not feel the RoboLeader display was helpful in the task.**
     Strongly DISAGREE |---|---|---|---|---|---| Strongly AGREE   N/A
                           1   2   3   4   5   6   7

6.   **I relied heavily on the RoboLeader for the task.**
     Strongly DISAGREE |---|---|---|---|---|---| Strongly AGREE   N/A
                           1   2   3   4   5   6   7

7.   **Threats were visible on the screen(s) long enough to accurately detect them.**
     Strongly DISAGREE |---|---|---|---|---|---| Strongly AGREE   N/A
                           1   2   3   4   5   6   7

8.   **The RoboLeader display was confusing.**
     Strongly DISAGREE |---|---|---|---|---|---| Strongly AGREE   N/A
                           1   2   3   4   5   6   7

9.   **The RoboLeader display was annoying.**
     Strongly DISAGREE |---|---|---|---|---|---| Strongly AGREE   N/A
                           1   2   3   4   5   6   7

10. **The RoboLeader display improved my performance on the task.**
     Strongly DISAGREE |---|---|---|---|---|---| Strongly AGREE   N/A
                           1   2   3   4   5   6   7

11. **The RoboLeader display can be deceptive.**
     Strongly DISAGREE |---|---|---|---|---|---| Strongly AGREE   N/A
                           1   2   3   4   5   6   7

12. **The RoboLeader display sometimes behaves in an unpredictable manner.**
     Strongly DISAGREE |---|---|---|---|---|---| Strongly AGREE   N/A
                           1   2   3   4   5   6   7

1

Usability & Trust Survey   **Comments**

13. I am often suspicious of the RoboLeader system's intent, action or outputs.
      Strongly DISAGREE |---|---|---|---|---|---| Strongly AGREE   N/A
                                 1   2   3   4   5   6   7

14. I am sometimes unsure of the RoboLeader system.
      Strongly DISAGREE |---|---|---|---|---|---| Strongly AGREE   N/A
                                 1   2   3   4   5   6   7

15. The RoboLeader system may have harmful effects on the task.
      Strongly DISAGREE |---|---|---|---|---|---| Strongly AGREE   N/A
                                 1   2   3   4   5   6   7

16. I am confident in the RoboLeader system.
      Strongly DISAGREE |---|---|---|---|---|---| Strongly AGREE   N/A
                                 1   2   3   4   5   6   7

17. The RoboLeader system can provide security.
      Strongly DISAGREE |---|---|---|---|---|---| Strongly AGREE   N/A
                                 1   2   3   4   5   6   7

18. The RoboLeader system has integrity.
      Strongly DISAGREE |---|---|---|---|---|---| Strongly AGREE   N/A
                                 1   2   3   4   5   6   7

19. The RoboLeader system is dependable.
      Strongly DISAGREE |---|---|---|---|---|---| Strongly AGREE   N/A
                                 1   2   3   4   5   6   7

20. The RoboLeader system is consistent.
      Strongly DISAGREE |---|---|---|---|---|---| Strongly AGREE   N/A
                                 1   2   3   4   5   6   7

21. I can trust the RoboLeader system.
      Strongly DISAGREE |---|---|---|---|---|---| Strongly AGREE   N/A
                                 1   2   3   4   5   6   7

22. I am familiar with the RoboLeader display.
      Strongly DISAGREE |---|---|---|---|---|---| Strongly AGREE   N/A
                                 1   2   3   4   5   6   7

2

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Appendix G. Situation Awareness Questions

This appendix appears in its original form, without editorial change.

Example 3 SA Questions
1) Use the provided paper to identify a route that was edited to avoid a fire
2) What was the compass direction (North, South, East, West) of your MGV prior to your last
      turn?

Mission 1 SA Questions
1) Use the provided paper to highlight an area that currently has a fire
2) Use the provided paper to identify where your UGV is currently located
3) Use the provided paper to identify one route that was edited to perform reconnaissance in an
      Area of Interest
4) Use the provided paper to identify the most recent change made to the route
5) What is currently happening in area X of your map?

Mission 2 SA Questions
1) What was your MGV's compass direction (North, South, East, West) prior to this blank
      screen?
2) Use the provided paper to identify the most recent change made to the route
3) Use the provided paper to identify one route that was edited to avoid a Hostile Area
4) Use the provided paper to highlight one Area of Interest
5) Use the provided paper to identify one route that has encountered smoke

Mission 3 SA Questions
1) Use the provided paper to identify where your UGV is currently located
2) What was the compass direction (North, South, East, West) of your MGV prior to your last
      turn?
3) Use the provided paper to highlight one Hostile Area
4) Use the provided paper to identify a route that was edited to avoid a fire
5) What is currently happening in area X of your map?

Appendix H. Participant SA Query Answer Sheets

This appendix appears in its original form, without editorial change.

I

Vehicle Spacing:
UAS (Raven) to UGV: 200 m
UGV to MGV: 50 m

1. _____

   _____

   _____

   _____

2. _____

   _____

   _____

   _____

Participant: _____   Date: _____   Mission 1 R S M

Maximum Vehicle Spacing:
UAS (Raven) to UGV: 200 m
UGV to MGV: 50 m

1. _____

   _____

   _____

   _____

2. _____

   _____

   _____

   _____

3. _____

   _____

   _____

   _____

4. _____

   _____

   _____

   _____

5. _____

   _____

   _____

Maximum Vehicle Spacing:
UAS (Raven) to UGV: 200 m
UGV to MGV: 50 m

1. _____

_____

_____

_____

2. _____

_____

_____

_____

3. _____

_____

_____

_____

4. _____

_____

_____

5. _____

_____

_____

Maximum Vehicle Spacing:
UAS (Raven) to UGV: 200 m
UGV to MGV: 50 m

1. _____

   _____

   _____

   _____

2. _____

   _____

   _____

   _____

3. _____

   _____

   _____

   _____

4. _____

   _____

   _____

   _____

5. _____

   _____

   _____

   _____
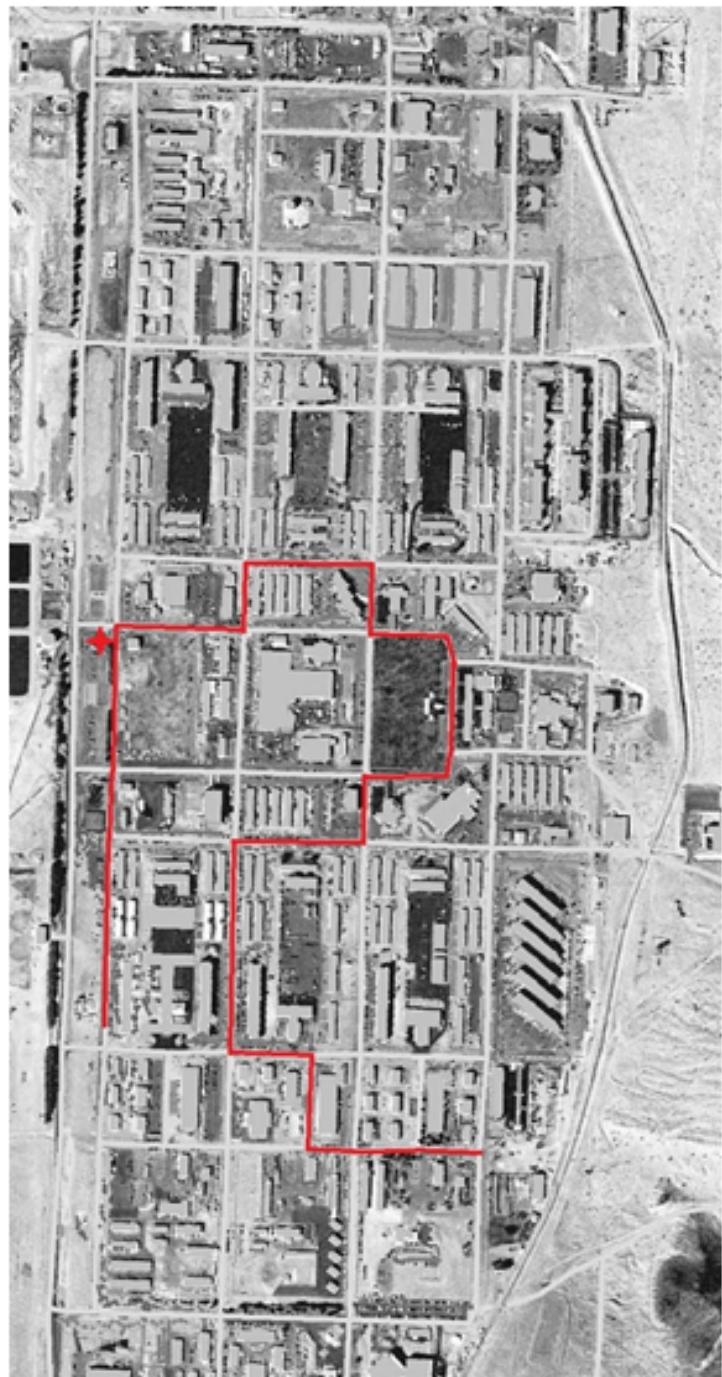
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Appendix I. Area of Interest (AOI) Detailed Results

I.1 AOI Analysis Method

In order to analyze participants' Area of Interest (AOI) usage, the following measures and behaviors were collected by eyetracker:

- Overall mission measures:

  o Total Time of mission

  o Total Dwell Time

- AOI specific measures (by mission):

  o Total Dwell Time

  o Number of Glances (Dwells)

  o Number of Fixations

  o Total Fixation Time

  o Duration of First Fixation

  o Entry Time of First Fixation (as mission time elapsed)

  o Sequence of First Fixation among all AOIs

  o Time to First Mouse Click

Several additional measures were calculated from the observed measures:
- Average Glance Duration (per AOI, by mission) – AOI Total Dwell Time divided by AOI Number of Glances, calculated for each mission condition.

- Average Fixation Duration (per AOI, by mission) – AOI Total Fixation Time divided by AOI Number of Fixations, calculated for each mission condition.

- Yes/No: did participant mouse click in this AOI?

Each AOI section has a brief explanation of its purpose and contents, expected participant interaction, and which analyses, if any, would be appropriate or informative for that particular AOI. Not all factors are examined for all AOIs. With some minor variation, analysis of each AOI was conducted in the following manner:

1. Repeated measures (within-subject) ANOVA was used to evaluate differences in Fixation and Glance behavior within the AOI due to mission condition.

2. Simple Linear Regression was used to evaluate if Fixation and Glance behavior was predictive of Target Detection Task performance, reported FAs, Perceived Workload and/or SA.

3. Individual difference factors Gaming Experience, PAC, SpAO, and SPAC were evaluated for correlations with Fixation and Glance behavior.

    a. A mixed between-within subjects ANOVA was used to further investigate and define significant correlations found in step 3.

4. Clicking Behavior was evaluated for correlation with Target Detection, FAs and Individual Difference factors. Clicking behavior for all participants is reported as percentages.

    a. Significant correlations for 2×2 tables (Individual Difference factors) were verified using Chi-squared analysis, Yates' Correction for Continuity.

    b. Significant correlations for continuous data (Target Detection and FAs) were further defined using Simple Linear Regression.

I.2 AOI 1 Map

AOI 1 (Map) was expected to have a high number of fixations and dwells, due to its size (21.5% of total screen area), position, and utility. The participant could manipulate the view displayed in this AOI, and this AOI was used to manage the convoy route and vehicle spacing, as well as to gather information needed to maintain SA. The number of fixations and total dwell time in this AOI was expected to vary with mission condition, with the highest number being in the Manual condition due to an additional task (Vehicle Spacing) that was automated in the RoboLeader conditions and, as such, was perfectly confounded with condition. For these reasons, AOI 1 eye tracker information was not analyzed in more depth.

I.3 AOIs 2 through 6

AOIs 2–6 are informational and task management in nature, meaning participants did not need to actively monitor these AOIs for information but instead look to them when directed by either incoming message notifications or their current task. As a result, total fixations and glances for AOIs 2–6 are relatively low in number, even though collectively these AOIs comprise 17.7% of the total screen area.

I.4 AOI 2 Message Center

AOI 2 was the incoming message center, where the participants received instruction or intelligence reports from either mission command or RoboLeader. Incoming messages notify the participant of changes to be made to the convoy route, and are accompanied by both an audible signal and visual signals (the Replan button in AOI 3 begins flashing yellow and the affected area highlights in AOI 1 Map). Each mission had six route changes, and according to table 3, AOI 2 averaged only four Glances in the Manual and Semi-Autonomous conditions, while it averaged nine Glances in the Fully Autonomous condition. This indicates that when workload levels were high, participants did not read the incoming intell message, but instead relied upon the audio prompts and color-coded signals that appeared on the Map to review route change requests.

Repeated measures analysis of variance (ANOVA) showed there was a significant effect of Mission Automation Condition on Fixation Count in AOI 2, Wilks' $\lambda = 0.653$, $F(2, 28) = 7.447$, $p = 0.003$, *partial $\eta^2 = 0.347$* (figure 1-15). There were significantly more fixations in AOI 2 in the Fully Autonomous condition ($M = 16.933$) than in either the Manual ($M = 6.033$; $\Delta M = 10.900$, $p = 0.001$) or the Semi-Autonomous Conditions ($M = 8.467$; $\Delta M = 8.467$, $p = 0.006$). Fixation Count in AOI 2 appeared to be inversely related to Perceived Workload, whereas in high workload conditions (Manual and Semi-Autonomous) the participant used AOI 2 only when directed, but in the reduced workload condition (Fully Autonomous) the participant did not wait for system notification but instead adopted a more proactive monitoring behavior.
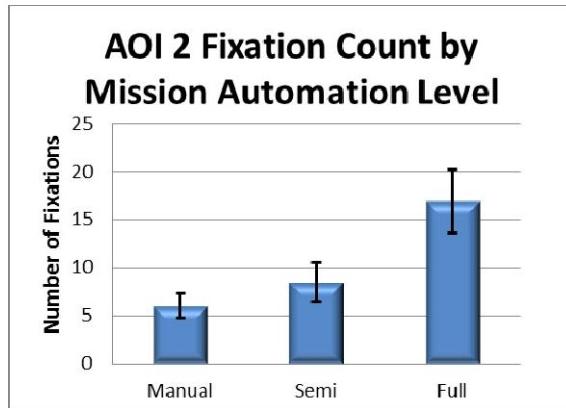
Figure I-1. AOI 2: fixation count by LOA.

I.5 AOI 3 Replan – Accept/Reject – Continue

AOI 3 was used to begin and end the route replan activity, as well as to accept or reject RoboLeader suggested route changes during the Fully Autonomous Mission Condition. All participants used this AOI as part of their route management tasks. There was no information to be gained by the participant by monitoring this AOI, and the buttons in this AOI were only active during route management. For these reasons, AOI 3 usage data were not analyzed in more depth.

I.6 AOI 4 Edit Route Dialogue

AOI 4 was used to make the modifications to the convoy route, as well as pause/resume individual vehicle movement for the vehicle spacing task. The edit route buttons were activated by clicking the Replan button in AOI 3, and were deactivated by clicking the Continue button in AOI 3. The Pause/Resume button was active during the Manual Condition when the participant was responsible for maintaining vehicle spacing of the convoy, but not during either RoboLeader condition. The participant would gain no information by monitoring this AOI, as no incoming information or notices appeared in this AOI. For these reasons, AOI 4 usage data were not analyzed in more depth.

I.7 AOI 5 Start – Undo – Threat

AOI 5 contained the Start, Undo, and Threat buttons. The Start button is used to begin the mission and is unused afterward. The Threat button would flash yellow as a visual confirmation whenever the participant clicked on a threat, however clicking on the Threat button had no effect. The Undo button was used if the participant felt they had identified a non-threat as a threat. The participant could immediately click the Undo button to note their mistake, and it would only remove the mouse click immediately preceding the Undo click from the data. Clicking the Undo button did not remove the threat icon from the Map. The participant would gain no information by monitoring this AOI, as no incoming information or notices appeared in this AOI. For these reasons, AOI 5 usage data were not analyzed in more depth.

I.8 AOI 6 Vehicle List

AOI 6 showed the list of vehicles, where the experimenter assigned which camera feed would appear in which AOI. Once the camera feeds were properly loaded, there would be no need for either the experimenter or operator to interact further with this AOI during the mission. For this reason, AOI 6 usage data were not analyzed in more depth.

I.9 AOI 7 UAS Camera Feed

AOI 7 contained the UAS camera feed, which the participant was required to monitor to maintain SA of the surrounding areas. No target detection tasks were associated with this feed, nor could the view be manipulated by the participant, so it was not expected that participants would click in this AOI. It was expected that the participants with the highest SA scores would have the most fixations and longest dwell times among users in this AOI. Simple Linear Regression analysis indicated Glance and Fixation behavior in AOI 7 was not predictive of SA scores (table I-1).

Table I-1. AOI 7 usage: eye movement relation to SA scores.

	Manual			Semi			Full		
	Beta	t	Sig.	Beta	t	Sig.	Beta	t	Sig.
Glance Count	−0.957	−0.689	0.498	−1.016	−0.803	0.431	−1.533	−1.097	0.286
Avg Glance Duration	−0.090	−0.226	0.823	−0.362	−0.790	0.438	−0.445	−1.086	0.291
Fixation Count	2.503	0.834	0.413	0.240	0.090	0.929	2.711	0.689	0.499
Avg Fixation Duration	0.451	0.994	0.331	0.115	0.276	0.785	−0.035	−0.084	0.934

I.9.1 LOA

There was a significant main effect of LOA in AOI 7 on both Fixation Count, Wilks' $\lambda = 0.590$, $F(2, 27) = 9.395$, $p = 0.001$, partial $\eta^2 = 0.410$, and Glance Count, Wilks' $\lambda = 0.618$, $F(2, 27) = 8.345$, $p = 0.002$, partial $\eta^2 = 0.382$. The Manual Condition had significantly fewer Fixations and Glances than either RoboLeader condition (figure I-1).
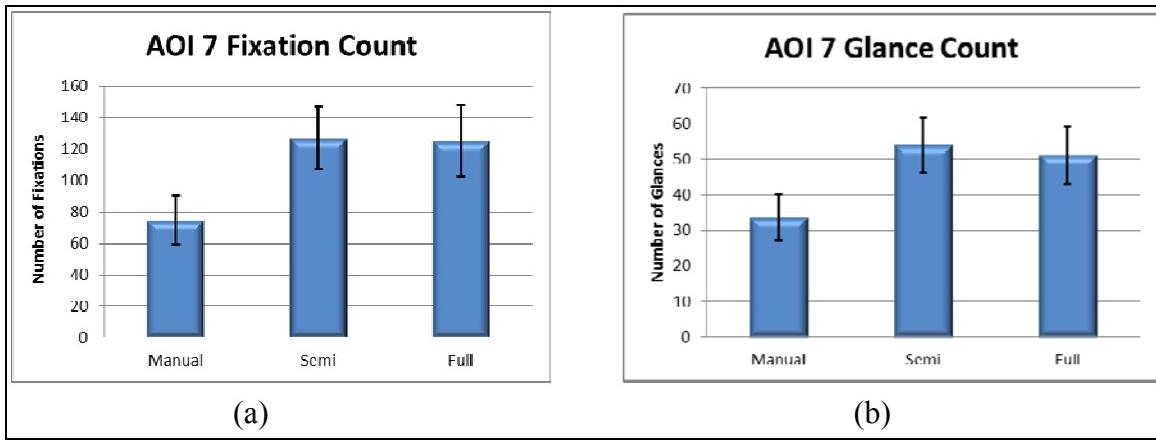
Figure I-2. AOI 7 fixations (a) and glances (b) across LOAs.

I.9.2 Individual Difference Factors

The individual difference factor Gaming Experience was positively correlated with Fixation Count and Glance Count in AOI 7 in the RoboLeader conditions (table I-2), but not SpAO, PAC, or SpAC, regardless of condition. Average Fixation Duration and Average Glance Duration were not significantly correlated with any individual difference measures in AOI 7.

Table I-2. AOI 7 usage: gaming experience correlations with fixation and glance behavior, by LOA.

		Gaming Experience			
		Glances Count	Avg Glance Duration	Fix Count	Avg Fixation Duration
Manual	Pearson's r	0.214	−0.118	0.252	−0.038
	Sig. (2-tailed)	0.255	0.534	0.179	0.843
Semi	Pearson's r	0.400[a]	0.123	0.386[a]	0.107
	Sig. (2-tailed)	0.028	0.525	0.035	0.581
Full	Pearson's r	0.415[a]	0.029	0.402[a]	−0.099
	Sig. (2-tailed)	0.023	0.884	0.028	0.623

[a] Correlation is significant at the 0.05 level (2-tailed).

There was no significant interaction between Gaming Experience and LOA on Fixation Count, Wilks' $\lambda = 0.881$, $F(2, 27) = 1.830$, $p = 0.180$, *partial* $\eta^2 = 0.119$, nor between Gaming Experience and LOA on Glance Count, Wilks' $\lambda = 0.870$, $F(2, 27) = 2.022$, $p = 0.152$, *partial* $\eta^2 = 0.152$.

There was a significant between-subjects effect of Gaming Experience on Fixation Count, $F(1, 28) = 5.413$, $p = 0.027$, *partial* $\eta^2 = 0.162$ (figure I-3a), and Glance Count, $F(1, 28) = 5.419$, $p = 0.027$, *partial* $\eta^2 = 0.162$ (figure I-3b). Frequent Action Gamers had made significantly more Fixations and Glances in AOI 7 than All Other Gamers.
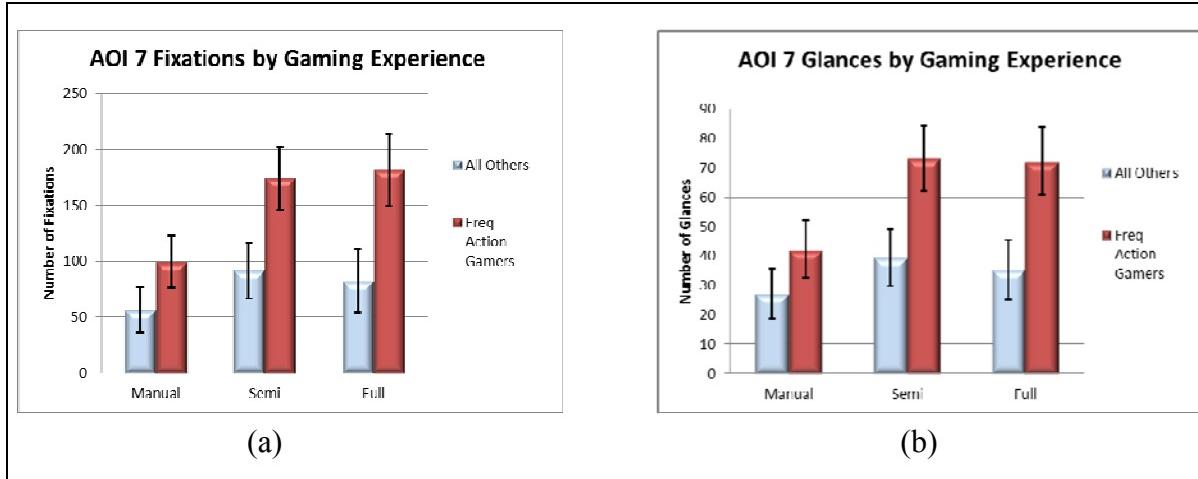
Figure I-3. AOI 7 fixations (a) and glances (b) by gaming experience, across LOAs.

I.10 AOI 8 UGV Camera Feed

AOI 8 contained the UGV camera feed, which gave the participant an advanced view of what the convoy would be encountering ahead. This view could not be manipulated by the participant, however, this AOI could be used in the target detection task to mark threats by clicking on them, so it was expected that individuals who scored well on the target detection task and had the fewest FAs would utilize this AOI towards that end. Simple Linear Regression analysis indicated Average Fixation Duration was predictive of Target Detection Scores in the Fully Autonomous condition (table I-3), and Glance and Fixation behavior in AOI 8 was not predictive of FAs, regardless of condition (table I-4).

Table I-3. AOI 8 fixation and glance behavior for target detection task, across LOAs.

	Manual			Semi			Full		
	Beta	t	Sig.	Beta	t	Sig.	Beta	t	Sig.
Glance Count	−2.267	−1.373	0.183	−0.360	−0.163	0.872	−0.709	−0.902	0.377
Avg Glance Duration	−0.734	−1.392	0.178	−0.108	−0.151	0.882	0.667	1.594	0.126
Fixation Count	4.468	1.146	0.264	0.994	0.320	0.752	1.436	0.992	0.332
Avg Fixation Duration	0.742	1.470	0.156	0.128	0.213	0.834	−0.980	−2.323	0.030

Table I-4. AOI 8 fixation and glance behavior for FAs, across LOAs.

	Manual			Semi			Full		
	Beta	t	Sig.	Beta	t	Sig.	Beta	t	Sig.
Glance Count	−1.665	−1.064	0.299	2.849	1.489	0.151	1.431	1.564	0.133
Avg Glance Duration	−0.634	−1.268	0.218	0.271	0.435	0.668	0.444	0.912	0.372
Fixation Count	2.333	0.632	0.534	−4.289	−1.592	0.126	−0.896	−0.532	0.600
Avg Fixation Duration	0.122	0.256	0.801	−0.467	−0.896	0.380	−0.113	−0.229	0.821

I.10.1 LOA

There was a significant main effect of LOA in AOI 8 on both Fixation Count, Wilks' $\lambda = 0.523$, $F(2, 28) = 12.771$, $p < 0.001$, *partial* $\eta^2 = 0.477$, and Glance Count, Wilks' $\lambda = 0.540$, $F(2, 28) = 11.902$, $p < 0.001$, *partial* $\eta^2 = 0.460$. The Manual Condition had significantly fewer Fixations and Glances than either RoboLeader condition (figure I-4).
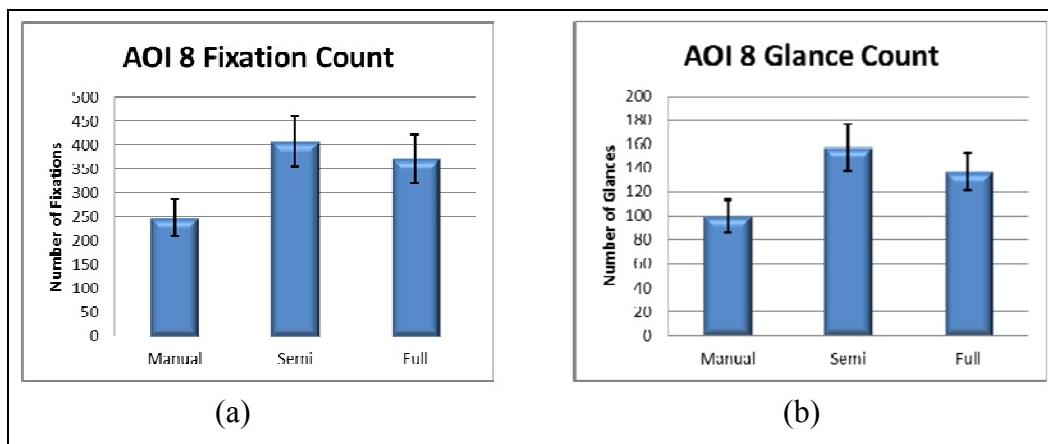
Figure I-4. AOI 8 fixations (a) and glances (b) across LOAs.

I.10.2 Individual Difference Factors

PAC was not correlated with Fixation and Glance behavior in AOI 8. SpAC was positively correlated with Average Glance Duration in AOI 8 in the Manual Condition only, $r = 0.403$, $p = 0.027$, *2-tailed*. Glance Count and Fixation Count in AOI 8 were moderately correlated with SpAO in the RoboLeader conditions (table I-5), but not the Manual condition. Glance Count and Fixation Count were positively correlated with Gaming Experience in the RoboLeader conditions (table I-6), but not the Manual condition.

Table I-5. AOI 8 usage: SpAO correlations with fixation and glance behavior, by LOA.

Spatial Ability Orientation (SpAO)		Glances Count	Avg Glance Duration	Fix Count	Avg Fixation Duration
Manual	Pearson's r	0.225	−0.068	0.208	−0.126
	Sig. (2-tailed)	0.233	0.723	0.271	0.506
Semi	Pearson's r	0.346	0.079	0.335	0.074
	Sig. (2-tailed)	0.061	0.678	0.071	0.699
Full	Pearson's r	0.373[a]	−0.019	0.357	−0.177
	Sig. (2-tailed)	0.042	0.922	0.053	0.357

[a] Correlation is significant at the 0.05 level (2-tailed).

Table I-6. AOI 8 usage: gaming experience correlations with fixation and glance behavior, by LOA.

Gaming Experience		Glances Count	Avg Glance Duration	Fix Count	Avg Fixation Duration
Manual	Pearson's r	0.228	−0.035	0.234	−0.112
	Sig. (2-tailed)	0.225	0.855	0.213	0.557
Semi	Pearson's r	0.395[a]	0.057	0.403[a]	0.027
	Sig. (2-tailed)	0.031	0.763	0.027	0.889
Full	Pearson's r	0.393[a]	0.003	0.407[a]	−0.140
	Sig. (2-tailed)	0.032	0.987	0.026	0.468

[a] Correlation is significant at the 0.05 level (2-tailed).

I.10.3 SpAC

There was a marginally significant interaction between SpAC and LOA on Average Glance Duration, Wilks' $\lambda = 0.822$, $F(2, 26) = 2.813$, $p = 0.078$, *partial $\eta^2 = 0.178$*. In the Manual Condition, participants who scored higher on the Spatial Ability Cube Comparison test made, on average, longer duration glances into AOI 8 than those who scored lower (figure I-5), but this difference was not significant for the RoboLeader conditions.
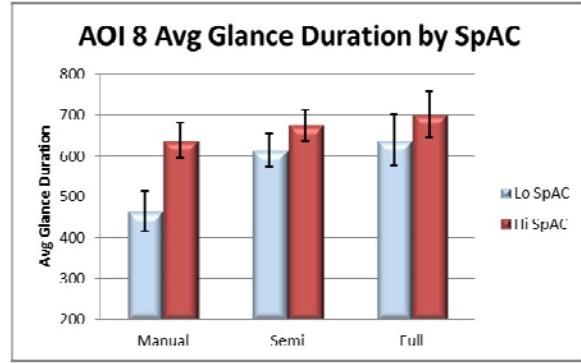
Figure I-5. AOI 8 average glance duration by SpAC,
across LOAs.

I.10.4 SpAO

There was no significant interaction between SpAO and LOA on Fixation Count, Wilks' $\lambda = 0.863$, $F(2, 27) = 2.145$, $p = 0.137$, *partial $\eta^2 = 0.137$*, nor between SpAO and LOA on Glance Count, Wilks' $\lambda = 0.876$, $F(2, 27) = 1.907$, $p = 0.168$, *partial $\eta^2 = 0.124$*.

There was a marginally significant between-subjects effect of SpAO on Fixation Count, $F(1, 28) = 3.462$, $p = 0.073$, *partial $\eta^2 = 0.110$*, and Glance Count, $F(1, 28) = 3.740$, $p = 0.063$, *partial $\eta^2 = 0.118$* (figure I-6). Participants with High SpAO made more Fixations and Glances in AOI 8 than those with Low SpAO, across all LOA.
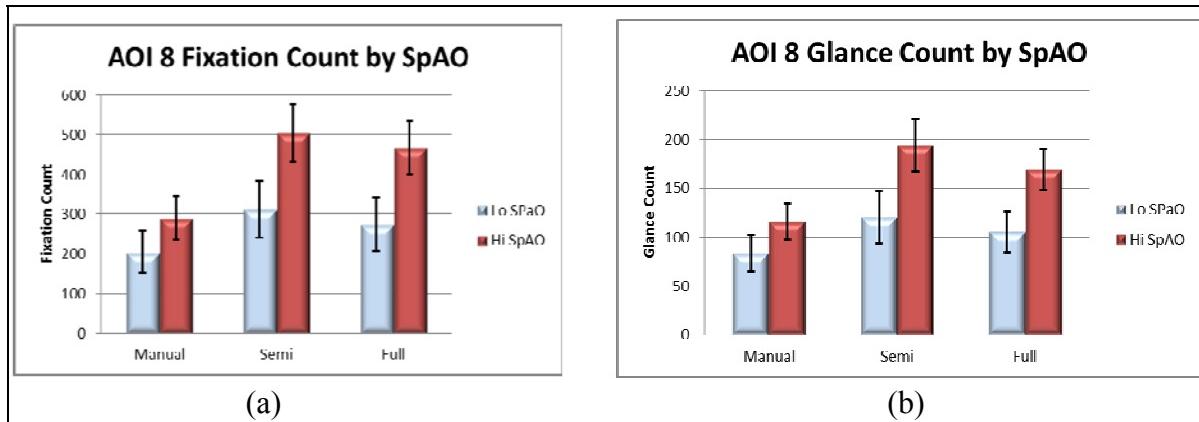
Figure I-6. AOI 8 fixations (a) and glances (b) by SpAO, across LOAs.

I.10.5 Gaming Experience

There was no significant interaction between Gaming Experience and LOA on Fixation Count, Wilks' $\lambda = 0.807$, $F(2, 27) = 3.237$, $p = 0.055$, *partial $\eta^2 = 0.193$*, or between Gaming Experience and LOA on Glance Count, Wilks' $\lambda = 0.831$, $F(2, 27) = 2.752$, $p = 0.082$, *partial $\eta^2 = 0.169$*.

There was a significant between-subjects effect of Gaming Experience on Fixation Count, $F(1, 28) = 4.908$, $p = 0.035$, *partial* $\eta^2 = 0.149$, and Glance Count, $F(1, 28) = 4.5149$, $p = 0.043$, *partial* $\eta^2 = 0.139$ (figure I-7). Frequent Action Gamers had made significantly more fixations and glances in AOI 8 than All Other Gamers, however, the Average Duration of their fixations and glances were not different from All Other Gamers.
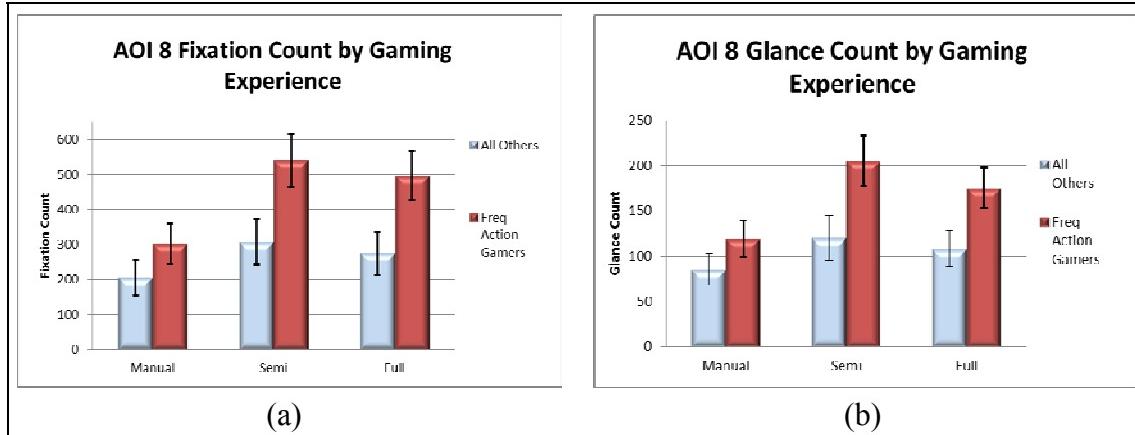
Figure I-7. AOI 8 fixations (a) and glances (b) by gaming experience, across LOAs.

I.10.6 Clicking Behavior

Gaming Experience was also positively correlated with whether the participant clicked in the AOI in the Fully Autonomous condition, $r = 0.381$, $p = 0.038$, *2-tailed*, and moderately correlated in the Manual condition, $r = 0.321$, $p = 0.083$, *2-tailed*, but not correlated in the Semi-Autonomous condition, $r = 0.247$, $p = 0.188$, *2-tailed*. Chi-Squared statistical analysis (using Yates' Correction for Continuity) of the likelihood of Gaming Experience affecting Clicking Behavior in AOI 8 indicated the groups were not significantly different, (Manual: $X^2(1, 30) = 1.926$, $p = 0.165$; Semi: $X^2(1, 30) = 0.956$, $p = 0.328$; Fully: $X^2(1, 30) = 2.868$, $p = 0.090$). It is interesting to note that among the Frequent Action Gamers the number of participants that did or did not click in the AOI was roughly evenly split in each condition, while the number of All Other Gamers who did not click in AOI 8 was consistently higher in every mission condition (figure I-8). Target Detection performance was not correlated with clicking behavior in any Mission Condition.
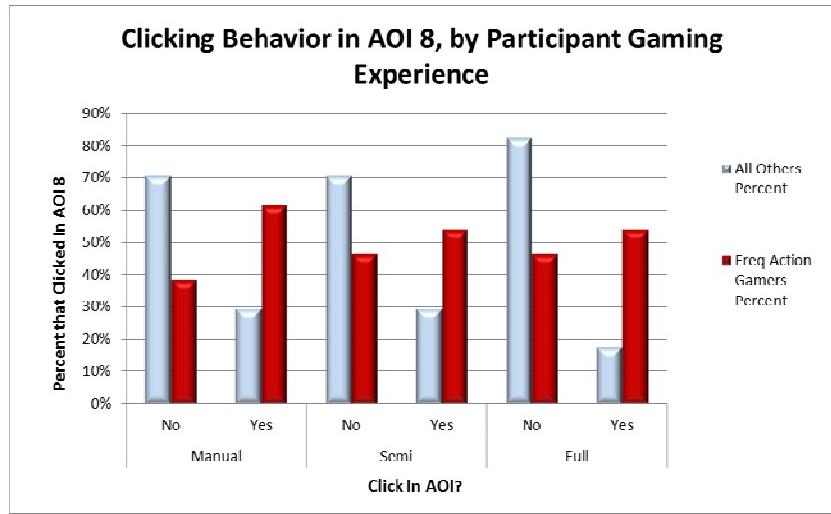
Figure I-8. Percent of participants that clicked in AOI 8, sorted by gaming experience, across LOAs.

I.11 AOIs 9, 10, and 11: MGV Forward 180° Camera Feed

AOIs 9, 10 and 11 comprise the MGV forward 180° camera feed, and collectively account for 21.3% of the screen area. Objects appear on the horizon in AOI 10 (straight ahead), then as the vehicles approach the object moves from AOI 10 into either AOI 9 (on the right) or 11 (on the left) before disappearing from the forward camera feeds. The views in these AOIs cannot be manipulated by the participant, and monitoring these feeds was essential for identifying threats for the target detection task, as well as maintaining SA. It was expected that AOI 10 will have more fixations and dwells than either 9 or 11, primarily due to its central location and proximity to AOI 1. It was also expected that participants who utilized all three AOIs for the target detection task will have higher scores and fewer FAs than those who did not.

I.12 AOI 9 MGV Forward Right

Simple Linear Regression analysis indicated that Fixation and Glance behavior in AOI 9 was not predictive of performance on the Target Detection Task (table I-7) or of FAs (table I-8), regardless of mission condition.

Table I-7. AOI 9 fixation and glance behavior for target detection across LOAs.

	Manual			Semi			Full		
	Beta	**t**	**Sig.**	**Beta**	**t**	**Sig.**	**Beta**	**t**	**Sig.**
Glance Count	1.875	0.873	0.392	−0.420	−0.321	0.751	−1.637	−1.088	0.288
Avg Glance Duration	1.158	0.871	0.393	−1.038	−1.365	0.186	−1.320	−1.274	0.216
Fixation Count	−1.150	−0.410	0.686	−1.204	−0.610	0.548	2.774	1.596	0.125
Avg Fixation Duration	−1.239	−0.951	0.352	0.038	0.056	0.955	0.355	0.554	0.585

Table I-8. AOI 9 fixation and glance behavior for FAs across LOAs.

	Manual			Semi			Full		
	Beta	**t**	**Sig.**	**Beta**	**t**	**Sig.**	**Beta**	**t**	**Sig.**
Glance Count	−3.423	−1.666	0.110	0.186	0.119	0.906	−1.002	−0.603	0.553
Avg Glance Duration	−2.226	−1.749	0.094	−0.058	−0.064	0.949	−0.681	−0.595	0.558
Fixation Count	2.713	1.011	0.323	−0.620	−0.265	0.794	0.773	0.402	0.691
Avg Fixation Duration	1.794	1.439	0.164	−0.270	−0.340	0.737	−0.057	−0.081	0.936

I.12.1 LOA

There was a significant main effect of LOA on Fixation Count, Wilks' $\lambda = 0.371$, $F(2, 28) = 23.781$, $p < 0.001$, *partial $\eta^2 = 0.629$* (figure I-9a), and Glance Count, Wilks' $\lambda = 0.357$, $F(2, 28) = 25.193$, $p < 0.001$, *partial $\eta^2 = 0.643$* (figure I-9b). There were significantly fewer Fixations and Glances in AOI 9 in the Manual condition than in the RoboLeader conditions.


(a)   (b)
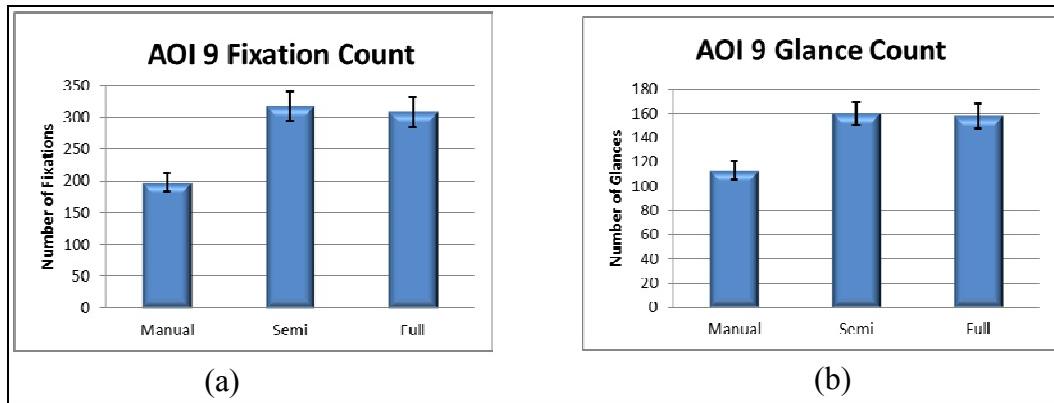
Figure I-9. AOI 9 fixation count (a) and glance count (b) across LOAs.

There was a significant main effect of LOA on Average Fixation Duration, Wilks' $\lambda = 0.767$, F (2, 28) = 4.244, $p = 0.025$, *partial* $\eta^2 = 0.233$ (figure 10a), and Average Glance Duration, Wilks' $\lambda = 0.546$, F (2, 28) = 11.654, $p < 0.001$, *partial* $\eta^2 = 0.454$ (figure 10b). Fixations and Glances in AOI 9 were significantly shorter in the Manual condition than in the RoboLeader conditions.
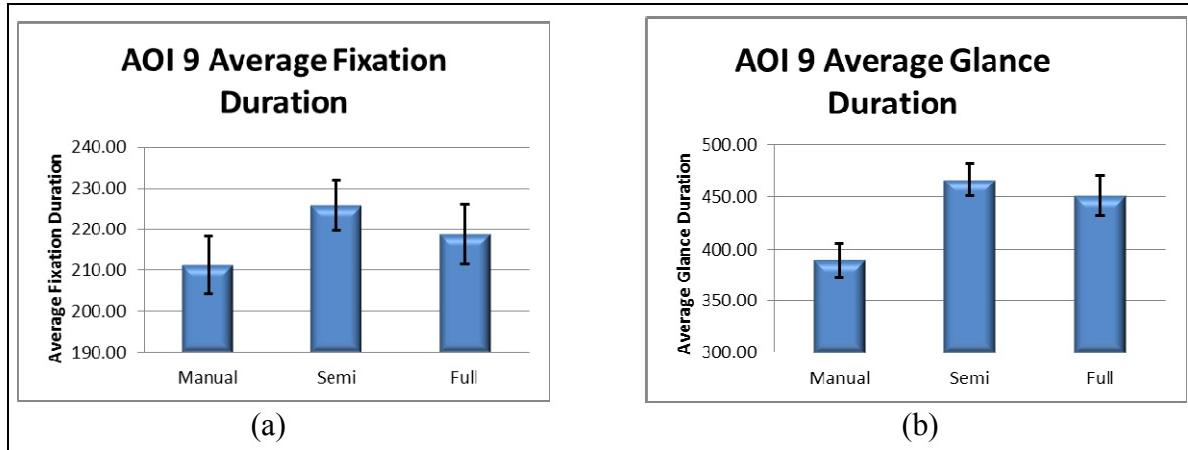
Figure I-10. AOI 9 average fixation duration (a) and average glance duration (b) across LOAs.

I.12.2 Individual Difference Factors

Average Glance Duration and Average Fixation Duration were moderately negatively correlated with PAC scores (table I-9) in the Fully Autonomous condition, but not in the Manual or Semi-Autonomous conditions. Glance Count and Fixation Count in AOI 9 were negatively correlated with SpAC scores in the Semi-Autonomous condition (table I-10), but not the Manual or Fully Autonomous conditions. Average Glance Duration in AOI 9 was negatively correlated with SpAO scores (table I-11) in the Manual and Fully Autonomous conditions, but not in the Semi-Autonomous condition. Gaming Experience was not correlated with Fixation or Glance behavior in AOI 9.

Table I-9. AOI 9 usage: PAC correlations with fixation and glance behavior by LOA.

		Attentional Control (PAC)			
		Glances Count	Avg Glance Duration	Fix Count	Avg Fixation Duration
Manual	Pearson's r	−0.025	0.223	0.012	0.140
	Sig. (2-tailed)	0.898	0.236	0.949	0.462
Semi	Pearson's r	0.144	0.260	0.218	0.070
	Sig. (2-tailed)	0.448	0.166	0.247	0.714
Full	Pearson's r	0.139	0.365[a]	0.186	0.360
	Sig. (2-tailed)	0.464	0.047	0.325	0.051

[a] Correlation is significant at the 0.05 level (2-tailed).

Table I-10. AOI 9 usage: SpAC correlations with fixation and glance behavior by
LOA.

Spatial Ability Cube Comparison (SpAC)					
		Glances Count	Avg Glance Duration	Fix Count	Avg Fixation Duration
Manual	Pearson's r	−0.054	0.319	−0.022	0.324
	Sig. (2-tailed)	0.776	0.086	0.907	0.081
Semi	Pearson's r	−0.450[a]	0.062	−0.417[a]	0.212
	Sig. (2-tailed)	0.013	0.746	0.022	0.261
Full	Pearson's r	−0.286	−0.037	−0.285	0.021
	Sig. (2-tailed)	0.125	0.848	0.127	0.914

[a] Correlation is significant at the 0.05 level (2-tailed).

Table I-11. AOI 9 usage: SpAO correlations with fixation and glance behavior
by LOA.

Spatial Ability Orientation (SpAO)					
		Glances Count	Avg Glance Duration	Fix Count	Avg Fixation Duration
Manual	Pearson's r	−0.021	−0.390[a]	−0.134	−0.211
	Sig. (2-tailed)	0.911	0.033	0.479	0.264
Semi	Pearson's r	−0.001	−0.183	−0.096	−0.009
	Sig. (2-tailed)	0.997	0.334	0.614	0.963
Full	Pearson's r	−0.164	−0.468[b]	−0.301	−0.277
	Sig. (2-tailed)	0.388	0.009	0.106	0.138

[a] Correlation is significant at the 0.05 level (2-tailed).
[b] Correlation is significant at the 0.01 level (2-tailed).

I.12.3 PAC

There was no significant interaction between PAC and LOA on Average Fixation Duration,
Wilks' $\lambda = 0.900$, $F(2, 27) = 1.493$, $p = 0.243$, partial $\eta^2 = 0.100$, or between PAC and LOA on
Average Glance Duration, Wilks' $\lambda = 0.945$, $F(2, 27) = 0.787$, $p = 0.465$, partial $\eta^2 = 0.055$.

There was no significant between-subjects effect of PAC on Average Fixation Duration in AOI
9, $F(1, 28) = 1.600$, $p = 0.216$, partial $\eta^2 = 0.054$ (figure I-11a), however, there was a marginally
significant between-subjects effect on Average Glance Duration, $F(1, 28) = 3.721$, $p = 0.064$,
partial $\eta^2 = 0.117$ (figure I-11b). Participants with higher PAC scores had longer Glances in AOI
9 than those with low PAC scores, across all mission conditions.
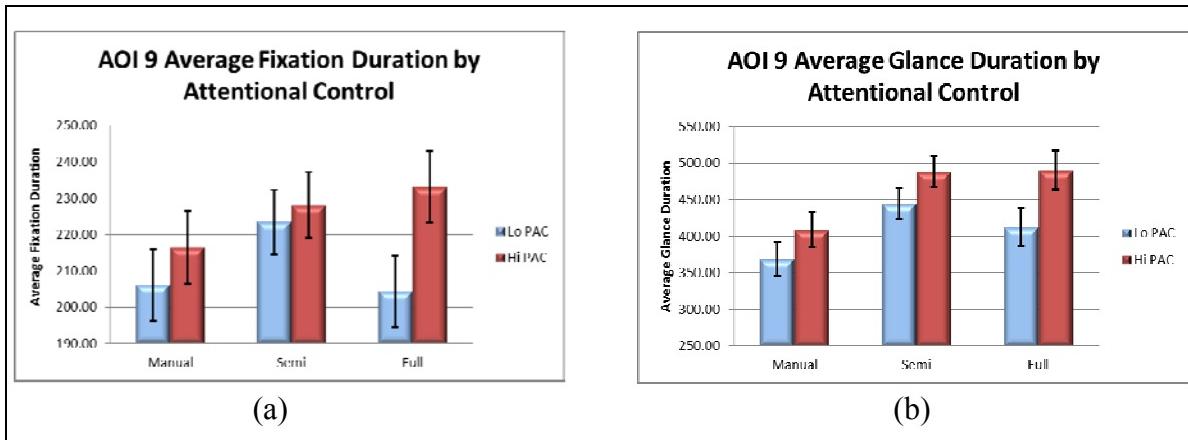
Figure I-11. AOI 9 average fixation duration (a) and average glance duration (b) by PAC, across LOAs.

I.12.4 SpAC

There was a significant interaction between SpAC and LOA on Fixation Count, Wilks' λ = 0.761, F (2, 27) = 4.233, p = 0.025, *partial η^2* = 0.239 (figure I-12a), as well as between SpAC and LOA on Glance Count, Wilks' λ = 0.751, F (2, 27) = 4.483, p = 0.021, *partial η^2* = 0.249 (figure I-12b). All participants had similar numbers of fixations and glances in AOI 9 during the Manual condition, however, participants who scored low on the Spatial Ability Cube Comparison Test had significantly more fixations and glances in AOI 9 in the RoboLeader conditions than those who scored high on the SpAC.
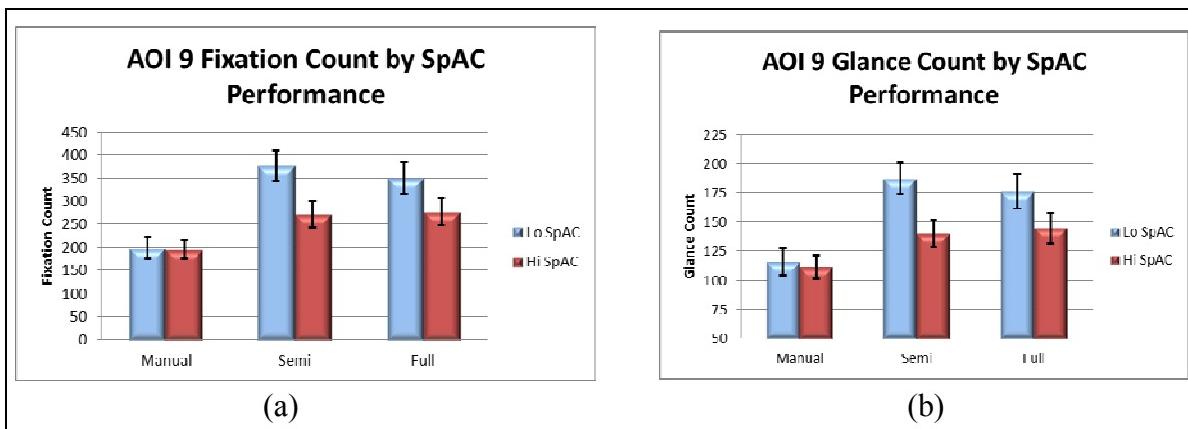
Figure I-12. AOI 9 fixations (a) and glances (b) by SpAC, across LOAs.

I.12.5 SpAO

There was no significant interaction between SpAO and LOA on Average Fixation Duration, Wilks' λ = 0.916, F (2, 27) = 1.231, p = 0.308, *partial η^2* = 0.084, or between SpAO and LOA on Average Glance Duration, Wilks' λ = 0.849, F (2, 27) = 2.396, p = 0.110, *partial η^2* = 0.151.

There was no significant between-subjects effect of SpAO on Average Fixation Duration, F (1, 28) = 1.216, p = 0.279, *partial η^2* = 0.042 (figure I-13a), however there was a significant between-subjects effect of SpAO on Average Glance Duration, F (1, 28) = 6.189, p = 0.019, *partial η^2* = 0.181 (figure I-13b). Participants low in SpAO had longer Glance Durations in AOI 9 than those with higher SpAO scores.
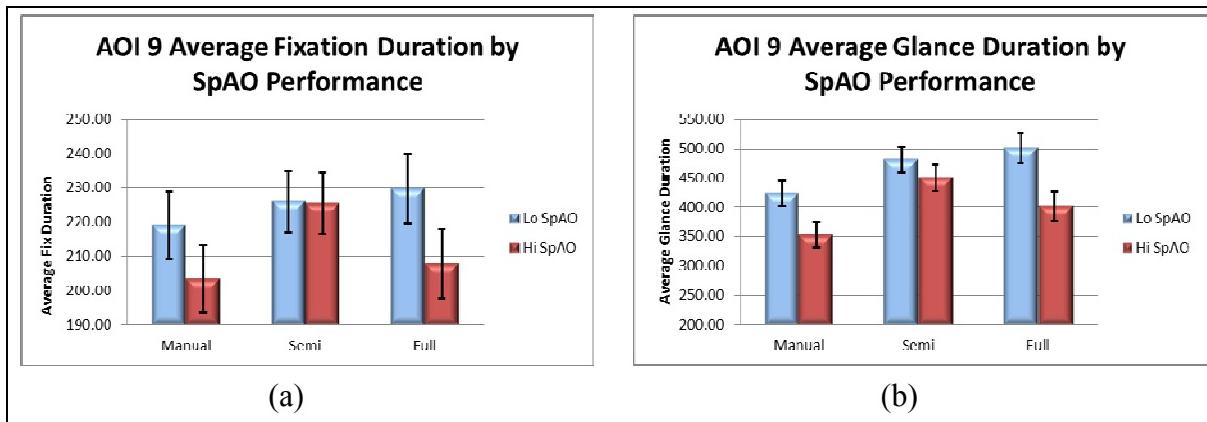
Figure I-13. AOI 9 average fixation duration (a) and average glance duration (b) by SpAO, across LOAs.

I.12.6 Clicking Behavior

Clicking Behavior in AOI 9 was not significantly correlated with performance on Target Detection Task or number of FAs, nor was it correlated with any individual difference measures. Overall, 81% of participants did click in AOI 9, with this percentage being lowest in the Manual condition (76.7%) and increasing as the level of automation assistance increased, Semi (80.0%), to the highest in the Fully Autonomous condition (86.7%), (figure I-14).
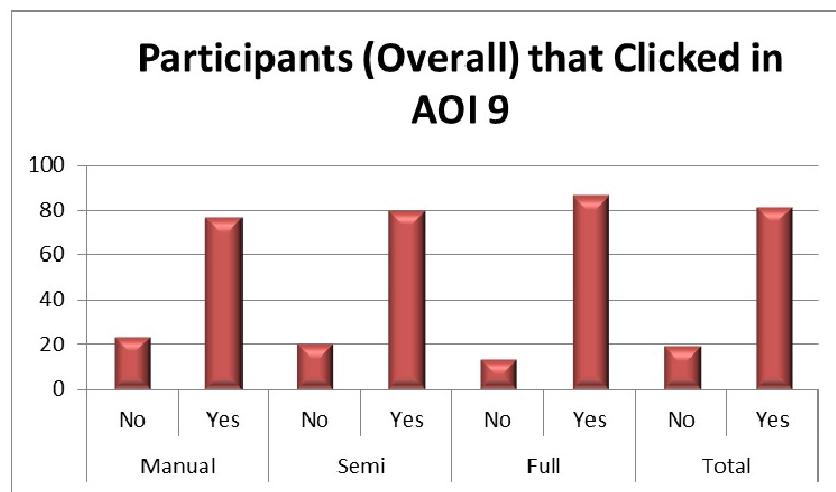
Figure I-14. Percent of participants that clicked in AOI 9 at least once, across LOAs.

I.13 AOI 10 MGV Forward Center

Simple Linear Regression analysis indicated that Fixation and Glance behavior in AOI 10 was not predictive of performance on the Target Detection Task (table I-12) or of FAs (table I-13), regardless of mission condition.

Table I-12. AOI 10 fixation and glance behavior for target detection, across LOAs.

|	Manual			Semi			Full		
	Beta	**t**	**Sig.**	**Beta**	**t**	**Sig.**	**Beta**	**t**	**Sig.**
Glance Count	0.224	0.185	0.855	0.395	0.400	0.693	−1.258	−1.828	0.081
Avg Glance Duration	0.348	0.337	0.739	−0.348	−0.364	0.719	−1.569	−1.988	0.059
Fixation Count	1.831	0.835	0.413	−1.622	−0.852	0.403	2.662	1.820	0.082
Avg Fixation Duration	0.531	0.670	0.510	−0.686	−0.686	0.500	1.012	1.269	0.218

Table I-13. AOI 10 fixation and glance behavior for FAs across LOAs.

	Manual			Semi			Full		
	Beta	**t**	**Sig.**	**Beta**	**t**	**Sig.**	**Beta**	**t**	**Sig.**
Glance Count	1.892	1.762	0.092	−0.753	−0.686	0.500	−0.841	−1.092	0.287
Avg Glance Duration	1.500	1.642	0.115	−0.499	−0.470	0.643	−0.078	−0.088	0.930
Fixation Count	−1.124	−0.579	0.568	−0.428	−0.203	0.841	−0.466	−0.285	0.779
Avg Fixation Duration	0.317	0.452	0.655	−0.284	−0.256	0.800	−0.855	−0.956	0.349

I.13.1 LOA

There was a significant main effect of LOA on Average Glance Duration, Wilks' $\lambda = 0.721$, $F(2, 28) = 5.424$, $p = 0.010$, partial $\eta^2 = 0.279$ (figure I-15). Average Glance Duration in AOI 10 was lowest in the Manual condition, highest in the RoboLeader conditions. There was no significant main effect of LOA on Average Fixation Duration, Wilks' $\lambda = 0.832$, $F(2, 28) = 2.828$, $p = 0.076$, partial $\eta^2 = 0.168$.
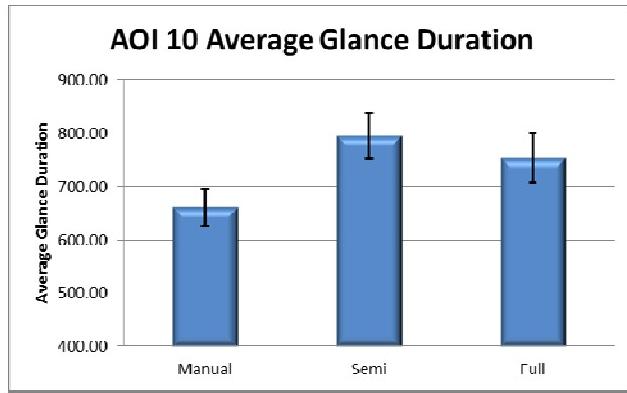
Figure I-15. AOI 10 average glance duration across LOAs.

I.13.2 Individual Difference Factors

PAC was not correlated with Fixation and Glance behavior in AOI 10. Average Glance Duration and Average Fixation Duration in AOI 10 were moderately correlated with SpAC scores (table I-14) in the Manual condition, but not in the Semi- or Fully Autonomous conditions. Average Glance Duration was negatively correlated with SpAO scores (table I-15) in the Fully Autonomous conditions but not in the Manual or Semi-Autonomous conditions. Average Fixation Duration in AOI 10 is negatively correlated with Gaming Experience (table I-16) in the Manual condition, but not in the Semi- or Fully Autonomous conditions.

Table I-14. AOI 10 usage: SpAC correlations with fixation and glance behavior by LOA.

Spatial Ability Cube Comparison (SpAC)							
		Glances Count	Total Glance Time	Avg Glance Duration	Fix Count	Total Fixation Time	Avg Fixation Duration
Manual	Pearson's r	0.101	0.347	0.340	0.276	0.348	0.316
	Sig. (2-tailed)	0.597	0.060	0.066	0.140	0.059	0.089
Semi	Pearson's r	0.033	−0.210	0.255	−0.079	0.043	0.262
	Sig. (2-tailed)	0.862	0.266	0.173	0.677	0.823	0.162
Full	Pearson's r	0.057	−0.181	0.203	−0.002	0.048	0.116
	Sig. (2-tailed)	0.765	0.339	0.282	0.992	0.800	0.540

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Table I-15. AOI 10 usage: SpAO correlations with fixation and glance behavior by LOA.

Spatial Ability Orientation (SpAO)							
		Glances Count	Total Glance Time	Avg Glance Duration	Fix Count	Total Fixation Time	Avg Fixation Duration
Manual	Pearson's r	0.160	−0.013	−0.147	0.048	−0.010	−0.222
	Sig. (2-tailed)	0.399	0.945	0.439	0.801	0.959	0.239
Semi	Pearson's r	−0.085	0.061	−0.233	−0.061	−0.089	−0.078
	Sig. (2-tailed)	0.654	0.750	0.216	0.749	0.639	0.682
Full	Pearson's r	−0.276	−0.037	−0.398[a]	−0.248	−0.261	−0.163
	Sig. (2-tailed)	0.140	0.846	0.029	0.187	0.164	0.390

[a] Correlation is significant at the 0.05 level (2-tailed).

Table I-16. AOI 10 usage: gaming experience correlations with fixation and glance behavior by LOA.

Gaming Experience							
		Glances Count	Total Glance Time	Avg Glance Duration	Fix Count	Total Fixation Time	Avg Fixation Duration
Manual	Pearson's r	−0.167	−0.222	−0.057	−0.127	−0.238	−0.381[a]
	Sig. (2-tailed)	0.377	0.239	0.763	0.505	0.204	0.038
Semi	Pearson's r	−0.068	0.039	−0.081	0.042	−0.090	−0.199
	Sig. (2-tailed)	0.721	0.837	0.670	0.824	0.635	0.291
Full	Pearson's r	0.104	0.166	0.042	0.189	0.095	−0.105
	Sig. (2-tailed)	0.583	0.380	0.826	0.318	0.619	0.579

[a] Correlation is significant at the 0.05 level (2-tailed).

I.13.3 SpAC

There was no significant interaction between SpAC and LOA on Average Fixation Duration, Wilks' $\lambda = 0.960$, $F\,(2, 27) = 0.567$, $p = 0.574$, partial $\eta^2 = 0.040$, nor Average Glance Duration, Wilks' $\lambda = 0.996$, $F\,(2, 27) = 0.058$, $p = 0.944$, partial $\eta^2 = 0.004$. There was no significant between-subjects effect of SpAC on Average Fixation Duration, $F\,(1, 28) = 2.048$, $p = 0.163$, partial $\eta^2 = 0.068$, or Average Glance Duration, $F\,(1, 28) = 2.782$, $p = 0.106$, partial $\eta^2 = 0.090$.

I.13.4 SpAO

There was no significant interaction between SpAO and LOA on Average Glance Duration, Wilks' $\lambda = 0.854$, $F\,(2, 27) = 2.305$, $p = 0.119$, partial $\eta^2 = 0.146$. There was no significant between-subjects effect of SpAO on Average Glance Duration in AOI 10, $F\,(1, 28) = 3.056$, $p = 0.091$, partial $\eta^2 = 0.098$.

I.13.5 Gaming Experience

There was no significant interaction between Gaming Experience and LOA on Average Fixation Duration, Wilks' $\lambda = 0.939$, $F(2, 27) = 0.880$, $p = 0.426$, *partial η^2* = 0.061. There was no significant between-subjects effect of Gaming Experience on Average Fixation Duration, $F(1, 28) = 1.939$, $p = 0.175$, *partial η^2* = 0.065.

I.13.6 Clicking Behavior

Clicking Behavior in AOI 10 was correlated with performance on Target Detection Task in the Manual, $r = 0.410$, $p = 0.024$, *2-tailed,* and Semi-Autonomous, $r = 0.327$, $p = 0.077$, *2-tailed,* conditions, but not in the Fully Autonomous, $r = 0.254$, $p = 0.175$, *ns,* condition. Clicking Behavior in AOI 10 was not correlated with the number of FAs in any condition, or with any individual difference measures. Overall, 93% of participants did click in AOI 10, with this percentage being lowest in the Manual condition (90%) and higher in the RoboLeader conditions; Semi (96.7%), and Fully Autonomous condition (93.3%), (figure I-16).
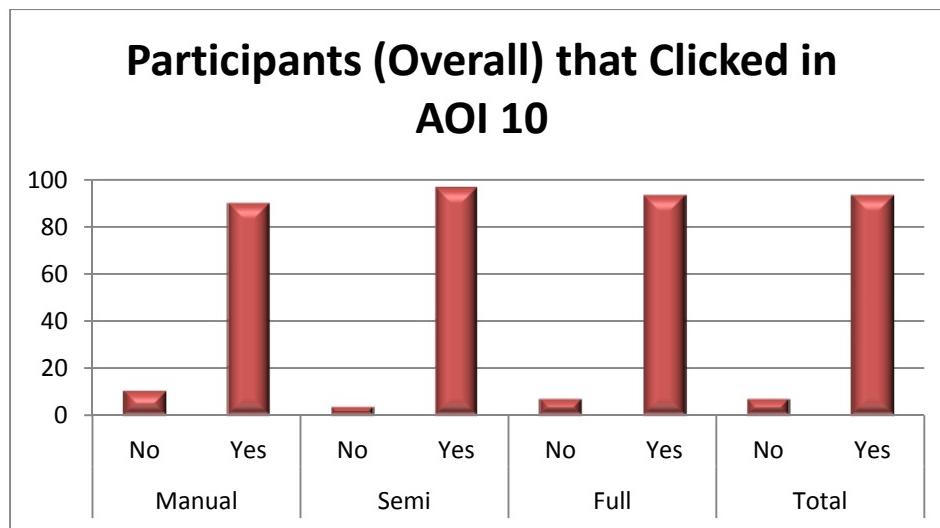

Figure I-16. Percent of participants that clicked in AOI 10 at least once, across LOAs.

I.14 AOI 11 MGV Forward Left

Simple Linear Regression analysis indicated that Fixation and Glance behavior in AOI 11 was not predictive of performance on the Target Detection Task (table I-17) or of FAs (table I-18), regardless of mission condition.

Table I-17. AOI 11 fixation and glance behavior for target detection across LOAs.

	Manual			Semi			Full		
	Beta	**t**	**Sig.**	**Beta**	**t**	**Sig.**	**Beta**	**t**	**Sig.**
Glance Count	−0.375	−0.219	0.828	0.591	0.317	0.754	−1.061	−1.348	0.192
Avg Glance Duration	0.278	0.279	0.783	0.078	0.072	0.943	−0.726	−1.305	0.205
Fixation Count	1.437	0.611	0.547	−2.762	−1.054	0.303	2.845	1.645	0.114
Avg Fixation Duration	0.051	0.054	0.957	−1.099	−0.984	0.336	0.195	0.428	0.673

Table I-18. AOI 11 fixation and glance behavior for FAs across LOAs.

	Manual			Semi			Full		
	Beta	**t**	**Sig.**	**Beta**	**t**	**Sig.**	**Beta**	**t**	**Sig.**
Glance Count	−0.114	−0.073	0.942	1.548	0.897	0.380	0.885	0.990	0.333
Avg Glance Duration	−0.402	−0.443	0.662	0.776	0.770	0.450	0.809	1.280	0.214
Fixation Count	0.277	0.129	0.898	4.034	1.660	0.111	0.634	0.323	0.750
Avg Fixation Duration	0.730	0.855	0.402	1.468	1.417	0.170	−0.461	−0.888	0.384

I.14.1 LOA

There was no significant main effect of LOA on Average Fixation Duration, Wilks' $\lambda = 0.860$, F $(2, 28) = 2.274$, $p = 0.122$, *partial $\eta^2 = 0.140$*, however there was a significant main effect of LOA on Average Glance Duration, Wilks' $\lambda = 0.683$, $F (2, 28) = 6.499$, $p = 0.005$, *partial $\eta^2 = 0.317$* (figure I-17). While Average Fixation Duration in AOI 11 was consistent throughout LOA, the Average Glance Duration in both of the RoboLeader conditions was significantly higher than those in the Manual condition.
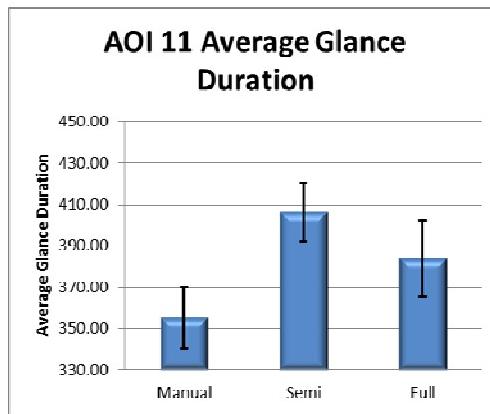

Figure I-17. AOI 11 average glance duration
across LOAs.

There was a significant main effect of LOA on Fixation Count, Wilks' $\lambda = 0.429$, $F (2, 28) = 18.612$, $p < 0.001$, *partial $\eta^2 = 0.571$* (figure I-18a) and Glance Count, Wilks' $\lambda = 0.438$, $F (2,$

28) $= 17.969$, $p < 0.001$, *partial* $\eta^2 = 0.562$ (Figure I-18b). Fixation and Glance Counts in AOI 11 was significantly lower in the Manual condition than for the RoboLeader conditions, across all participants.
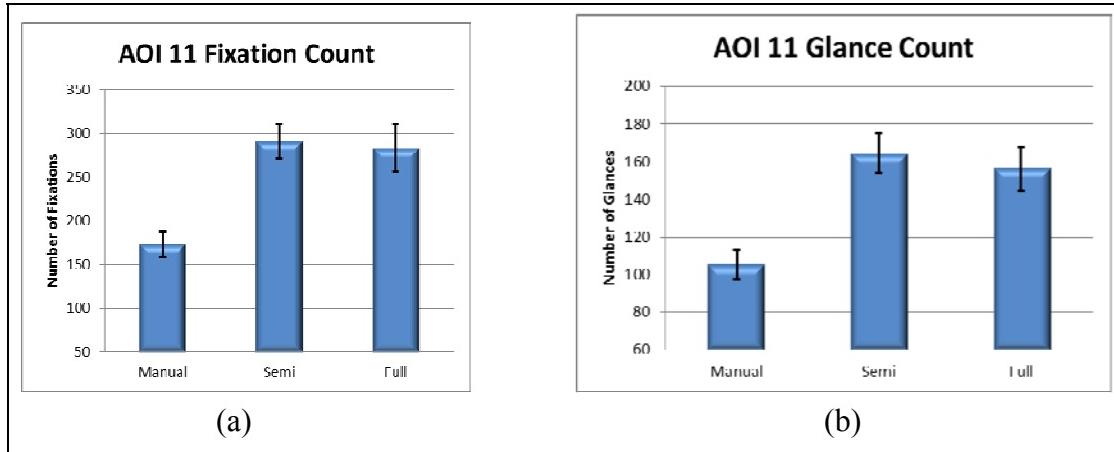

Figure I-18. AOI 11 average fixation duration (a) and average glance duration (b) across LOAs.

I.14.2 Individual Difference Factors

Fixation Count in AOI 11 was moderately correlated with PAC (table I-19) in the Manual condition, but not correlated in the Semi-Autonomous and Fully Autonomous conditions. Average Fixation Duration and Average Glance Duration were negatively correlated with SpAC scores (table I-20) in the Manual condition, but not correlated in the Semi-Autonomous and Fully Autonomous conditions. Fixation Count was also moderately correlated with AOI 11 usage in the Manual condition only. Average Glance Duration in AOI 11 was negatively correlated with SpAO scores (table I-21) in the Manual condition, but not correlated in the Semi-Autonomous and Fully Autonomous conditions. Average Fixation Duration and Average Glance Duration in AOI 11 were negatively correlated with Gaming Experience (table I-22) in the Manual condition, moderately negatively correlated in the Semi-Autonomous condition, and not correlated in the Fully Autonomous condition.

Table I-19. AOI 11 usage: PAC correlations with fixation and glance behavior by LOA.

		Glances Count	Total Glance Time	Avg Glance Duration	Fix Count	Total Fixation Time	Avg Fixation Duration
Attentional Control							
Manual	Pearson's r	−0.256	−0.254	−0.165	−0.317	−0.233	0.009
	Sig. (2-tailed)	0.172	0.176	0.383	0.088	0.215	0.961
Semi	Pearson's r	−0.072	−0.066	−0.052	−0.094	−0.061	0.058
	Sig. (2-tailed)	0.707	0.728	0.787	0.621	0.748	0.761
Full	Pearson's r	0.035	0.122	0.260	0.134	0.106	0.136
	Sig. (2-tailed)	0.853	0.519	0.165	0.481	0.576	0.474

Table I-20. AOI 11 usage: SpAC correlations with fixation and glance behavior by LOA.

		Glances Count	Total Glance Time	Avg Glance Duration	Fix Count	Total Fixation Time	Avg Fixation Duration
Spatial Ability Cube Comparison (SpAC)							
Manual	Pearson's r	0.292	0.413[a]	0.533[b]	0.357	0.406[a]	0.461[a]
	Sig. (2-tailed)	0.118	0.023	0.002	0.053	0.026	0.010
Semi	Pearson's r	−0.101	0.044	0.246	−0.046	0.025	0.146
	Sig. (2-tailed)	0.597	0.815	0.190	0.811	0.897	0.442
Full	Pearson's r	0.023	−0.027	−0.275	0.033	−0.037	−0.217
	Sig. (2-tailed)	0.902	0.887	0.141	0.862	0.846	0.249

[a] Correlation is significant at the 0.05 level (2-tailed).
[b] Correlation is significant at the 0.01 level (2-tailed).

Table I-21. AOI 11 usage: SpAO correlations with fixation and glance behavior by LOA.

Spatial Ability Orientation (SpAO)							
		Glances Count	Total Glance Time	Avg Glance Duration	Fix Count	Total Fixation Time	Avg Fixation Duration
Manual	Pearson's r	0.136	−0.059	−0.365[a]	−0.035	−0.060	−0.111
	Sig. (2-tailed)	0.473	0.756	0.048	0.854	0.754	0.559
Semi	Pearson's r	0.100	−0.009	−0.177	0.026	−0.036	−0.112
	Sig. (2-tailed)	0.601	0.961	0.349	0.893	0.849	0.555
Full	Pearson's r	0.035	0.163	0.148	0.122	0.151	0.048
	Sig. (2-tailed)	0.852	0.391	0.436	0.521	0.425	0.802

[a] Correlation is significant at the 0.05 level (2-tailed).

Table I-22. AOI 11 usage: gaming experience correlations with fixation and glance behavior by LOA.

Gaming Experience							
		Glances Count	Total Glance Time	Avg Glance Duration	Fix Count	Total Fixation Time	Avg Fixation Duration
Manual	Pearson's r	−0.053	−0.173	−0.374[a]	−0.080	−0.177	−0.439[a]
	Sig. (2-tailed)	0.781	0.361	0.042	0.674	0.349	0.015
Semi	Pearson's r	0.160	0.017	−0.231	0.130	−0.020	−0.312
	Sig. (2-tailed)	0.397	0.929	0.219	0.495	0.915	0.093
Full	Pearson's r	0.065	−0.113	−0.195	−0.037	−0.120	−0.195
	Sig. (2-tailed)	0.734	0.552	0.302	0.846	0.529	0.302

[a] Correlation is significant at the 0.05 level (2-tailed).

I.14.3 PAC

There was no significant interaction between PAC and LOA on Fixation Count, Wilks' λ = 0.900, F (2, 27) = 1.504, p = 0.240, partial η^2 = 0.100. There was no significant between-subjects effect of PAC on Fixation Count, F (1, 28) = 0.096, p = 0.759, partial η^2 = 0.003.

I.14.4 SpAC

There was a marginally significant interaction between SpAC and LOA on Average Fixation Duration, Wilks' λ = 0.802, F (2, 27) = 3.335, p = 0.051, partial η^2 = 0.198 (figure I-19). Participants who scored higher on the SpAC test had longer Fixations across all mission conditions, while participants who scored lower on the SpAC test had much shorter fixations in AOI 11 during the Manual mission condition. Low SpAC participants' Fixation Duration increased to near that of the High SpAC participants in the RoboLeader conditions. There was no

significant interaction between SpAC and LOA on Average Glance Duration, Wilks' $\lambda = 0.885$, $F(2, 27) = 1.748$, $p = 0.193$, *partial $\eta^2 = 0.115$*.
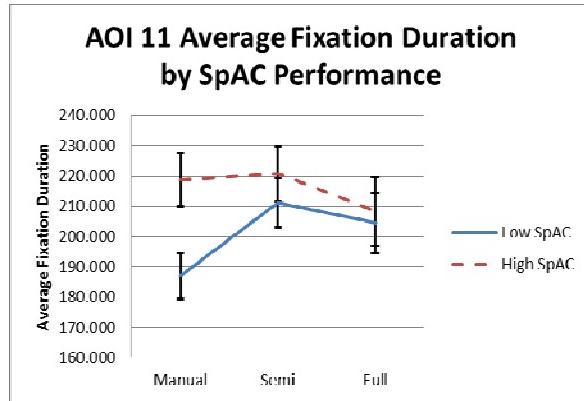

Figure I-19. Average fixation duration by SpAC, across LOAs.

There was a significant between-subjects effect of SpAC on Average Glance Duration, $F(1, 28) = 4.408$, $p = 0.045$, *partial $\eta^2 = 0.136$*, (figure I-20). Average Glance Duration was significantly shorter for low SpAC participants in AOI 11 than for high SPAC participants, across all Mission conditions.
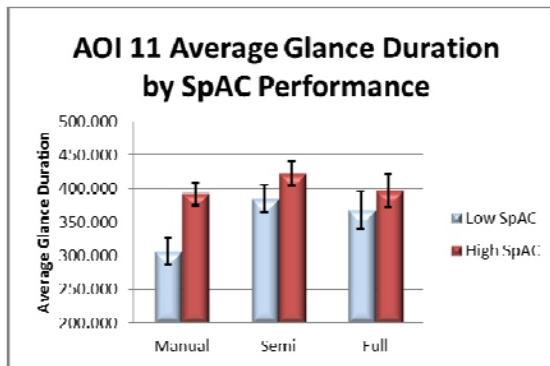
Figure I-20. AOI 11 average glance duration by SpAC, across LOAs.

I.14.5 SpAO

There was no significant interaction between SpAO and LOA on Average Glance Duration, Wilks' $\lambda = 0.944$, $F(2, 27) = 0.808$, $p = 0.456$, *partial $\eta^2 = 0.056$*.

There was a marginally significant between-subjects effect of SpAO on Average Glance Duration, $F(1, 28) = 3.628$, $p = 0.067$, *partial $\eta^2 = 0.115$* (figure I-21). Participants who scored low on the SpAO measure had significantly longer glances in AOI 11 than those with high SpAO scores, across all mission conditions.
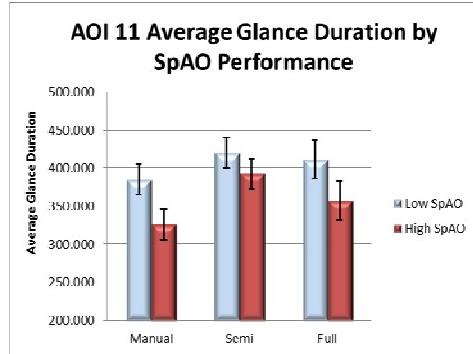
Figure I-21. AOI 11 average glance duration
by SpAO, across LOAs.

I.14.6 Gaming Experience

There were no significant interactions between Gaming Experience and LOA on Average Fixation Duration, Wilks' $\lambda = 0.951$, $F(2, 27) = 0.690$, $p = 0.510$, *partial $\eta^2 = 0.049$*, or Average Glance Duration, Wilks' $\lambda = 0.973$, $F(2, 27) = 0.373$, $p = 0.692$, *partial $\eta^2 = 0.027$*.

There was a significant between-subjects effect of Gaming Experience on Average Fixation Duration, $F(1, 28) = 4.409$, $p = 0.045$, *partial $\eta^2 = 0.136$* (figure I-22). Average Fixation Duration was significantly shorter for Frequent Action Gamers in AOI 11 than for Other Gamers, across all Mission conditions. There was no significant between-subjects effect of Gaming Experience on Average Glance Duration, $F(1, 28) = 3.284$, $p = 0.081$, *partial $\eta^2 = 0.105$*.
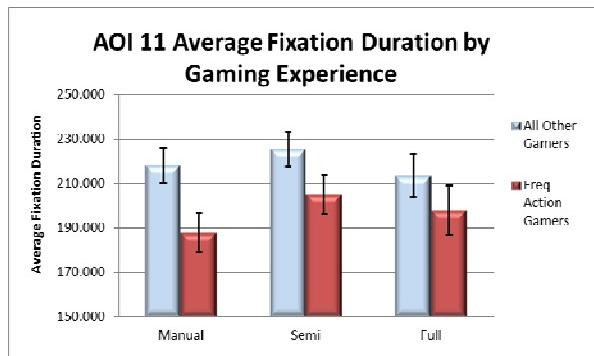

Figure I-22. AOI 11 average fixation duration by
gaming experience, across LOAs.

I.14.7 Clicking Behavior

Simple Linear Regression showed that Clicking behavior in AOI 11 was predictive of performance on the Target Detection Task for the Fully Autonomous condition ($\beta = 0.393$, $t(27) = 2.265$, $p = 0.031$), but not for the Manual ($\beta = 0.264$, $t(27) = 1.146$, $p = 0.159$) or Semi-Autonomous ($\beta = 0.206$, $t(27) = 1.010$, $p = 0.323$) conditions. Clicking Behavior was not

Correlated with any individual difference factors. The fewest participants clicked in AOI 11 in the Manual condition (66.7%), while the RoboLeader conditions Semi-Autonomous (83.3%) and Fully Autonomous (76.7%) had more usage (figure I-23).
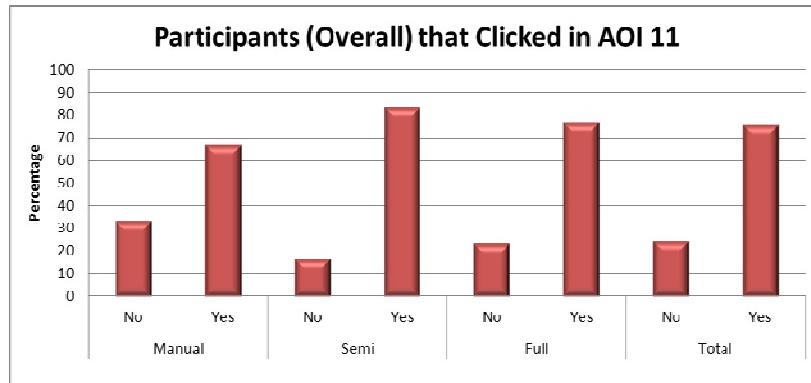

Figure I-23. Percent of participants that clicked in AOI 11 at least once, across LOAs.

I.15 AOIs 12, 13, and 14 - MGV Rearward 180° Camera Feed

AOIs 12, 13 and 14 comprise the MGV rearward 180° camera feed, and collectively account for 21.7% of the screen area. Objects appear along the periphery in either AOI 12 (on the right) or AOI 14 (on the left) before disappearing into the horizon in AOI 13 (straight ahead). The views in these AOIs could not be manipulated by the operator, and monitoring these feeds was essential for identifying threats for the target detection task, as well as maintaining SA. It was expected that AOI 13 would have more fixations and glances than either AOI 12 or AOI 14, primarily due to its central location and proximity to AOI 10. Monitoring these feeds was necessary for identifying threats for the target detection task, as some threats were only visible in this rearward view. As such, it was expected that participants who utilized all three AOIs for the target detection task would have higher scores and fewer FAs than those who did not.

I.16 AOI 12 MGV Rearward Right

Simple Linear Regression analysis indicated that Fixation Count, Glance Count, and Average Duration of Fixations and Glances in AOI 12 were not predictive of performance on the Target Detection Task (table I-23). Simple Linear Regression analysis indicated that Glance Count, Fixation Count, Average Glance Duration, and Average Fixation Duration in AOI 12 were all predicative of the number of FAs reported in the Manual condition, but not in the RoboLeader conditions (table I-24).

Table I-23. AOI 12 fixation and glance behavior for target detection across LOAs.

	Manual			Semi			Full		
	Beta	**t**	**Sig.**	**Beta**	**t**	**Sig.**	**Beta**	**t**	**Sig.**
Glance Count	1.645	0.979	0.338	1.095	0.794	0.436	−0.410	−0.316	0.755
Avg Glance Duration	0.680	0.819	0.421	0.119	0.186	0.854	−0.501	−0.869	0.394
Fixation Count	1.251	0.449	0.657	−3.801	−1.576	0.129	1.772	1.438	0.164
Avg Fixation Duration	−0.066	−0.096	0.924	−1.122	−1.317	0.201	0.028	0.060	0.953

Table I-24. AOI 12 fixation and glance behavior for FAs across LOAs.

	Manual			Semi			Full		
	Beta	**t**	**Sig.**	**Beta**	**t**	**Sig.**	**Beta**	**t**	**Sig.**
Glance Count	4.892	3.521	0.002	−0.352	−0.191	0.850	−0.373	−0.215	0.832
Avg Glance Duration	1.778	2.591	0.017	−0.216	−0.253	0.803	0.343	0.445	0.660
Fixation Count	−7.985	−3.472	0.002	−0.610	−0.190	0.851	−0.174	−0.106	0.917
Avg Fixation Duration	−1.059	−1.864	0.076	0.156	0.138	0.892	−0.507	−0.801	0.432

I.16.1 LOA

There was a significant main effect of LOA on Fixation Count, Wilks' $\lambda = 0.694$, $F(2, 28) = 6.182$, $p = 0.006$, *partial* $\eta^2 = 0.306$, (figure I-24a), as well as on Glance Count, Wilks' $\lambda = 0.738$, $F(2, 28) = 4.969$, $p = 0.014$, *partial* $\eta^2 = 0.262$, (figure I-24b). There were more Fixations and Glances in AOI 12 in the RoboLeader conditions than in the Manual condition.
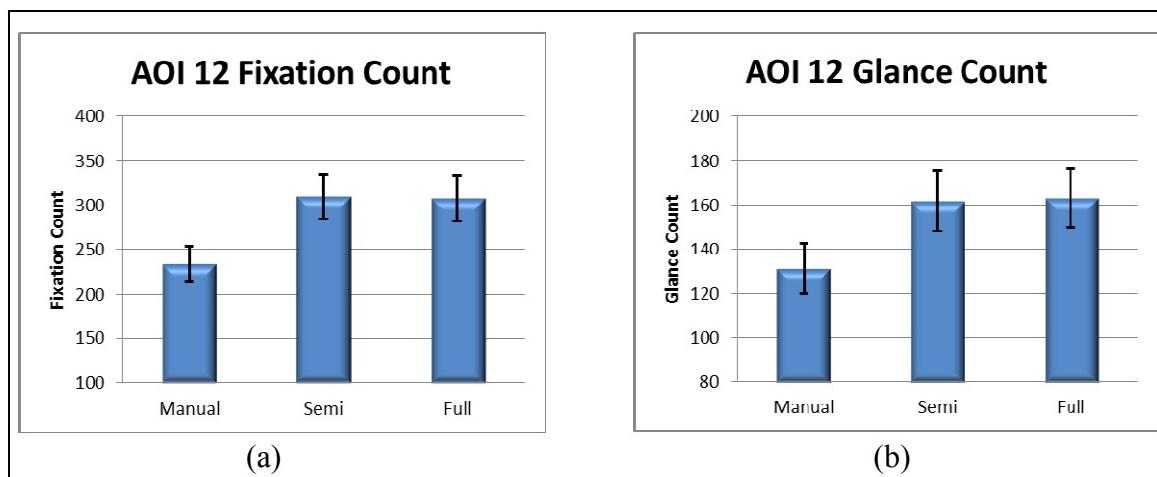

Figure I-24. AOI 12 fixation count (a) and glance count (b), across LOAs.

There was a marginally significant main effect of LOA on Average Glance Duration, Wilks' $\lambda = 0.815$, $F(2, 28) = 3.812$, $p = 0.057$, *partial $\eta^2 = 0.185$*. Average Glance Duration in AOI 12 was significantly longer in the Semi-Autonomous condition than in the Manual condition. Average Glance Duration was longer in the Fully Autonomous condition than in the Manual condition, but did not reach statistical significance (figure I-25).
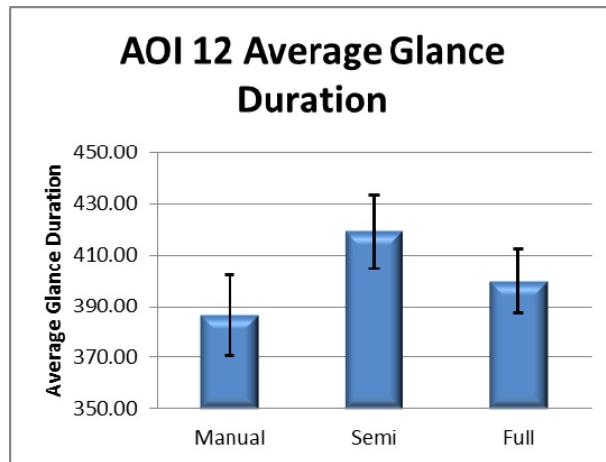

Figure I-25. AOI 12 average glance duration
across LOAs.

I.16.2 Individual Difference Factors

Average Glance Duration in AOI 12 was positively correlated with PAC in the Manual and Semi-Autonomous conditions, but not the Fully Autonomous condition (table I-25). Glance Count and Fixation Count in AOI 12 were negatively correlated with SpAC in all mission conditions (table I-26). Glance Count and Fixation Count in AOI 12 were moderately correlated with SpAO in the Semi-Autonomous condition, but not the Manual or Fully Autonomous conditions (table I-27). Gaming Experience was not correlated with Fixation and Glance behavior in AOI 12.

Table I-25. AOI 12 usage: PAC correlations with fixation and glance behavior by LOA.

		Glances Count	Total Glance Time	Avg Glance Duration	Fix Count	Total Fixation Time	Avg Fixation Duration
Manual	Pearson's r	−0.213	−0.022	0.394[a]	−0.069	−0.014	0.135
	Sig. (2-tailed)	0.258	0.910	0.031	0.717	0.940	0.476
Semi	Pearson's r	−0.130	0.029	0.384[a]	0.007	0.023	0.164
	Sig. (2-tailed)	0.493	0.881	0.036	0.972	0.904	0.387
Full	Pearson's r	−0.028	0.091	0.256	0.022	0.089	0.294
	Sig. (2-tailed)	0.883	0.633	0.172	0.908	0.640	0.114

[a] Correlation is significant at the 0.05 level (2-tailed).

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Table I-26. AOI 12 usage: SpAC correlations with fixation and glance behavior by LOA.

		Glances Count	Total Glance Time	Avg Glance Duration	Fix Count	Total Fixation Time	Avg Fixation Duration
Spatial Ability Cube Comparison (SpAC)							
Manual	Pearson's r	−0.377[a]	−0.189	0.211	−0.312	−0.156	0.301
	Sig. (2-tailed)	0.040	0.317	0.263	0.094	0.411	0.107
Semi	Pearson's r	−0.403[a]	−0.317	0.216	−0.382[a]	−0.295	0.231
	Sig. (2-tailed)	0.027	0.087	0.251	0.037	0.114	0.219
Full	Pearson's r	−0.467[b]	−0.462[a]	−0.089	−0.469[b]	−0.437[a]	0.020
	Sig. (2-tailed)	0.009	0.010	0.641	0.009	0.016	0.918

[a] Correlation is significant at the 0.05 level (2-tailed).
[b] Correlation is significant at the 0.01 level (2-tailed).

Table I-27. AOI 12 usage: SpAO correlations with fixation and glance behavior by LOA.

		Glances Count	Total Glance Time	Avg Glance Duration	Fix Count	Total Fixation Time	Avg Fixation Duration
Spatial Ability Orientation (SpAO)							
Manual	Pearson's r	0.167	0.065	−0.253	0.104	0.049	−0.087
	Sig. (2-tailed)	0.378	0.732	0.177	0.585	0.797	0.649
Semi	Pearson's r	0.340	0.349	0.030	0.317	0.333	0.116
	Sig. (2-tailed)	0.066	0.059	0.874	0.088	0.072	0.543
Full	Pearson's r	0.222	0.199	−0.091	0.180	0.196	−0.049
	Sig. (2-tailed)	0.239	0.292	0.634	0.342	0.300	0.798

I.16.3 PAC

There was no significant interaction between PAC and LOA on Average Glance Duration, Wilks' $\lambda = 0.948$, $F(2, 27) = 0.738$, $p = 0.488$, partial $\eta^2 = 0.052$.

There was a significant between-subjects effect of PAC on Average Glance Duration, $F(1, 28) = 5.822$, $p = 0.023$, partial $\eta^2 = 0.172$ (figure I-26). Participants with higher PAC scores had longer Glances in AOI 12 than those with lower PAC scores across all mission conditions.
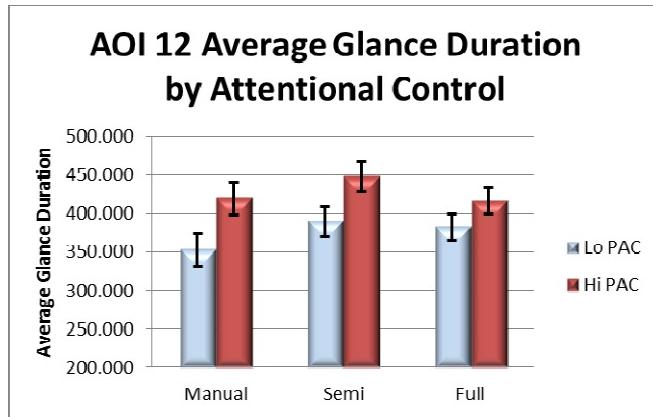
Figure I-26. AOI 12 average glance duration by
PAC, across LOAs.

I.16.4 SpAC

There was no significant interaction between SpAC and LOA on Fixation Count, Wilks'
$\lambda = 0.944$, $F(2, 27) = 0.806$, $p = 0.457$, *partial $\eta^2 = 0.056$*, nor between SpAC and LOA on
Glance Count, Wilks' $\lambda = 0.969$, $F(2, 27) = 0.433$, $p = 0.653$, *partial $\eta^2 = 0.031$*.

There was a significant between-subjects effect of SpAC on Fixation Count, $F(1, 28) = 7.974$,
$p = 0.009$, *partial $\eta^2 = 0.222$* (figure I-27a), and Glance Count, $F(1, 28) = 8.285$, $p = 0.008$,
partial $\eta^2 = 0.228$ (figure I-27b). Participants with lower SpAC scores had more Fixations and
Glances in AOI 12 across all mission conditions than those with higher SpAC scores, and had
significantly more Fixations and Glances in the RoboLeader conditions than in the Manual
condition. Fixation Count and Glance Count in AOI 12 were not significantly different between
mission conditions for participants with high SpAC scores.
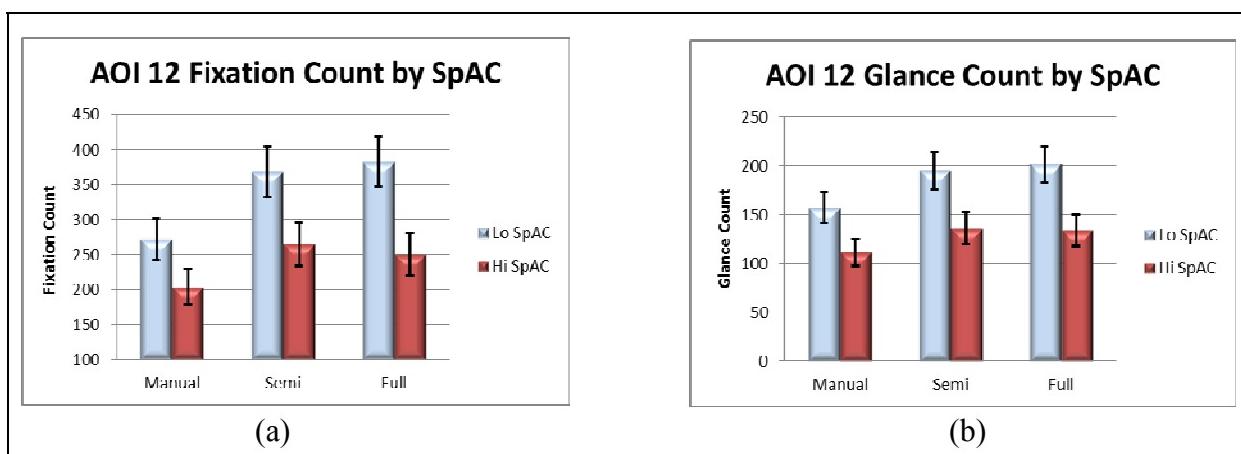
Figure I-27. AOI 12 usage: fixation count (a) and glance count (b) by SpAC, across LOAs.

I.16.5 SpAO

There was no significant interaction between SpAO and LOA on Fixation Count, Wilks' $\lambda = 0.926$, $F(2, 27) = 1.072$, $p = 0.356$, *partial* $\eta^2 = 0.074$, nor between SpAO and LOA on Glance Count, Wilks' $\lambda = 0.931$, $F(2, 27) = 0.994$, $p = 0.383$, *partial* $\eta^2 = 0.069$. There was not a significant between-subjects effect of SpAO on Fixation Count, $F(1, 28) = 1.826$, $p = 0.187$, *partial* $\eta^2 = 0.061$, or Glance Count, $F(1, 28) = 2.449$, $p = 0.129$, *partial* $\eta^2 = 0.080$ for AOI 12.

I.16.6 Clicking Behavior

Simple Linear Regression indicated that Clicking behavior in AOI 12 was predictive of performance on the Target Detection Task for the Fully Autonomous, $\beta = 0.351$, $t(27) = 1.983$, $p = 0.057$, and Semi-Autonomous, $\beta = 0.373$, $t(27) = 2.125$, $p = 0.043$, conditions, but not for the Manual condition, $\beta = -0.047$, $t(27) = -0.250$, $p = 0.804$. Clicking Behavior in AOI 12 was not correlated with any individual difference factors. Overall, 62% of participants did click in AOI 12, with this percentage being lowest in the Fully Autonomous condition (50%) and higher in the Manual (63%) and Semi-Autonomous (73%) conditions (figure I-28).
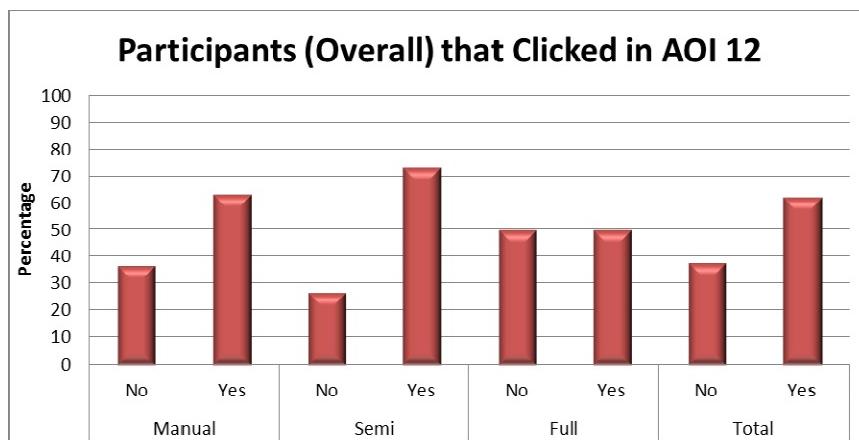
Figure I-28. Percent of participants that clicked in AOI 12 at least once, across LOAs.

I.17 AOI 13 MGV Rearward Center

Simple Linear Regression analysis indicated that Fixation and Glance behavior in AOI 13 was not predictive of performance on the Target Detection Task (table I-28) or of reported FAs (table I-29), regardless of condition.

Table I-28. AOI 13 fixation and glance behavior for target detection across LOAs.

	Manual			Semi			Full		
	Beta	**t**	**Sig.**	**Beta**	**t**	**Sig.**	**Beta**	**t**	**Sig.**
Glance Count	−2.207	−0.948	0.354	−1.422	−0.586	0.564	1.235	1.144	0.265
Avg Glance Duration	−0.618	−0.719	0.480	−0.851	−0.681	0.503	0.619	0.963	0.346
Fixation Count	7.583	1.449	0.161	1.458	0.435	0.668	−0.577	−0.405	0.689
Avg Fixation Duration	0.756	1.091	0.287	0.305	0.213	0.833	−0.911	−1.982	0.060

Table I-29. AOI 13 fixation and glance behavior for FAs across LOAs.

	Manual			Semi			Full		
	Beta	**t**	**Sig.**	**Beta**	**t**	**Sig.**	**Beta**	**t**	**Sig.**
Glance Count	0.395	0.163	0.872	1.746	0.636	0.532	−1.961	−1.299	0.207
Avg Glance Duration	−0.322	−0.360	0.722	0.864	0.611	0.547	−0.235	−0.261	0.796
Fixation Count	−2.848	−0.523	0.606	−3.908	−1.030	0.314	2.269	1.141	0.266
Avg Fixation Duration	−0.068	−0.094	0.926	−1.713	−1.058	0.302	0.062	0.096	0.924

I.17.1 LOA

There were no significant main effects of LOA on Fixation Count, Wilks' $\lambda = 0.974$, $F (2, 28) = 0.371$, $p = 0.693$, *partial η^2 = 0.026*; Glance Count, Wilks' $\lambda = 0.989$, $F (2, 28) = 0.156$, $p = 0.857$, *partial η^2 = 0.011*; Average Fixation Duration, Wilks' $\lambda = 0.903$, $F (2, 28) = 1.508$, $p = 0.239$, *partial η^2 = 0.097*; or Average Glance Duration, Wilks' $\lambda = 0.936$, $F (2, 28) = 0.953$, $p = 0.398$, *partial η^2 = 0.064* in AOI 13.

I.17.2 Individual Difference Factors

Average Glance Duration in AOI 13 was positively correlated with PAC in the Manual and Semi-Autonomous conditions, but not the Fully Autonomous condition (table I-30). Glance Count and Fixation Count in AOI 13 were negatively correlated with SpAC scores in all mission conditions (table I-31). Glance Count and Fixation Count in AOI 13 were moderately correlated with SpAO in the Semi-Autonomous condition, but not the Manual or Fully Autonomous conditions (table I-32). Gaming Experience was not correlated with Fixation and Glance behavior in AOI 13.

Table I-30. AOI 13 usage: PAC correlations with fixation and glance behavior by LOA.

Attentional Control					
		Glances Count	**Avg Glance Duration**	**Fix Count**	**Avg Fixation Duration**
Manual	Pearson's r	−0.213	0.394[a]	−0.069	0.135
	Sig. (2-tailed)	0.258	0.031	0.717	0.476
Semi	Pearson's r	−0.130	0.384[a]	0.007	0.164
	Sig. (2-tailed)	0.493	0.036	0.972	0.387
Full	Pearson's r	−0.028	0.256	0.022	0.294
	Sig. (2-tailed)	0.883	0.172	0.908	0.114

[a] Correlation is significant at the 0.05 level (2-tailed).

Table I-31. AOI 13 usage: SpAC correlations with fixation and glance behavior, by LOA.

Spatial Ability Cube Comparison (SpAC)					
		Glances Count	**Avg Glance Duration**	**Fix Count**	**Avg Fixation Duration**
Manual	Pearson's r	−0.377[a]	0.211	−0.312	0.301
	Sig. (2-tailed)	0.040	0.263	0.094	0.107
Semi	Pearson's r	−0.403[a]	0.216	−0.382[a]	0.231
	Sig. (2-tailed)	0.027	0.251	0.037	0.219
Full	Pearson's r	−0.467[b]	−0.089	−0.469[b]	0.020
	Sig. (2-tailed)	0.009	0.641	0.009	0.918

[a] Correlation is significant at the 0.05 level (2-tailed).
[b] Correlation is significant at the 0.01 level (2-tailed).

Table I-32. AOI 13 usage: SpAO correlations with fixation and glance behavior by LOAs.

Spatial Ability Orientation (SpAO)					
		Glances Count	**Avg Glance Duration**	**Fix Count**	**Avg Fixation Duration**
Manual	Pearson's r	0.167	−0.253	0.104	−0.087
	Sig. (2-tailed)	0.378	0.177	0.585	0.649
Semi	Pearson's r	0.340	0.030	0.317	0.116
	Sig. (2-tailed)	0.066	0.874	0.088	0.543
Full	Pearson's r	0.222	−0.091	0.180	−0.049
	Sig. (2-tailed)	0.239	0.634	0.342	0.798

I.17.3 PAC

There was no significant interaction between PAC and LOA on Average Glance Duration, Wilks' $\lambda = 0.883$, $F(2, 27) = 1.787$, $p = 0.187$, *partial $\eta^2 = 0.117$*. There was no significant between-subjects effect of PAC on Average Glance Duration for AOI 13, $F(1, 28) = 0.497$, $p = 0.487$, *partial $\eta^2 = 0.017$*.

I.17.4 SpAC

There were no significant interactions between SpAC and LOA on Fixation Count, Wilks' $\lambda = 0.924$, $F(2, 27) = 1.118$, $p = 0.342$, *partial $\eta^2 = 0.342$*, or between SpAC and LOA on Glance Count, Wilks' $\lambda = 0.940$, $F(2, 27) = 0.865$, $p = 0.432$, *partial $\eta^2 = 0.060$*.

There was no significant between-subjects effect of SpAC on Fixation Count, $F(1, 28) = 3.231$, $p = 0.083$, *partial $\eta^2 = 0.103$*. There was a marginally significant between-subjects effect of SpAC on Glance Count, $F(2, 27) = 3.694$, $p = 0.065$, *partial $\eta^2 = 0.117$*, (figure I-29). Participants with lower SpAC scores had more Glances in AOI 13 than those with higher SpAC scores across all mission conditions.
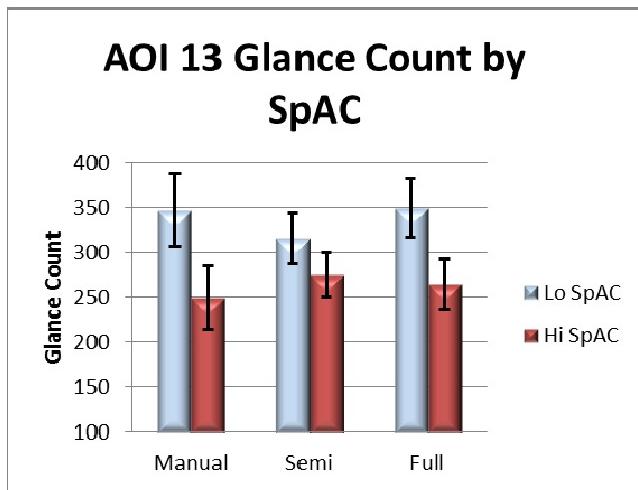
Figure I-29. AOI 13 usage: glance count by SpAC, across LOAs.

I.17.5 SpAO

There was no significant interaction between SpAO and LOA on Fixation Count, Wilks' $\lambda = 0.990$, $F(2, 27) = 0.140$, $p = 0.870$, *partial $\eta^2 = 0.010$*, or between SpAO and LOA on Glance Count, Wilks' $\lambda = 0.992$, $F(2, 27) = 0.103$, $p = 0.902$, *partial $\eta^2 = 0.008$*.

There were no significant between-subjects effect of SpAO on Fixation Count, $F(1, 28) = 0.228$, $p = 0.637$, *partial $\eta^2 = 0.008$*, or Glance Count, $F(2, 27) = 0.784$, $p = 0.383$, *partial $\eta^2 = 0.027$*.

I.17.6 Clicking Behavior

All participants in all mission conditions clicked in AOI 13. As such, Clicking Behavior in AOI 13 is a constant and could not be analyzed as predictive of any specific outcomes.

I.18 AOI 14 MGV Rearward Left

Simple Linear Regression analysis indicated that Fixation and Glance behavior in AOI 14 was not predictive of performance on the Target Detection Task (table I-33) or of FAs (table I-34), regardless of condition.

Table I-33. AOI 14 fixation and glance behavior for target detection across LOAs.

	Manual			Semi			Full		
	Beta	t	Sig.	Beta	t	Sig.	Beta	t	Sig.
Glance Count	−0.507	−0.278	0.783	1.454	1.038	0.309	−1.021	−0.892	0.381
Avg Glance Duration	−0.053	−0.110	0.913	0.161	0.227	0.822	−0.938	−1.727	0.096
Fixation Count	0.855	0.441	0.663	−1.256	−0.902	0.376	1.300	1.120	0.273
Avg Fixation Duration	−0.096	−0.213	0.833	−0.050	−0.098	0.923	0.417	0.992	0.331

Table I-34. AOI 14 fixation and glance behavior for FAs across LOAs.

	Manual			Semi			Full		
	Beta	t	Sig.	Beta	t	Sig.	Beta	t	Sig.
Glance Count	−0.359	−0.188	0.853	0.140	0.088	0.930	0.323	0.272	0.788
Avg Glance Duration	−0.418	−0.831	0.414	0.011	0.014	0.989	0.714	1.266	0.217
Fixation Count	0.519	0.255	0.801	−0.115	−0.073	0.942	−0.426	−0.354	0.727
Avg Fixation Duration	0.378	0.799	0.432	−0.144	−0.253	0.803	−0.555	−1.272	0.215

I.18.1 LOA

There was a marginally significant main effect of LOA on Fixation Count, Wilks' $\lambda = 0.825$, $F_{(2, 28)} = 2.961$, $p = 0.068$, partial $\eta^2 = 0.175$ (figure I-30a), and on Glance Count, Wilks' $\lambda = 0.812$, $F_{(2, 28)} = 3.241$, $p = 0.054$, partial $\eta^2 = 0.188$ (figure I-30b). Participants made fewer Fixations and Glances in AOI 14 in the Manual condition than in either of the RoboLeader conditions.
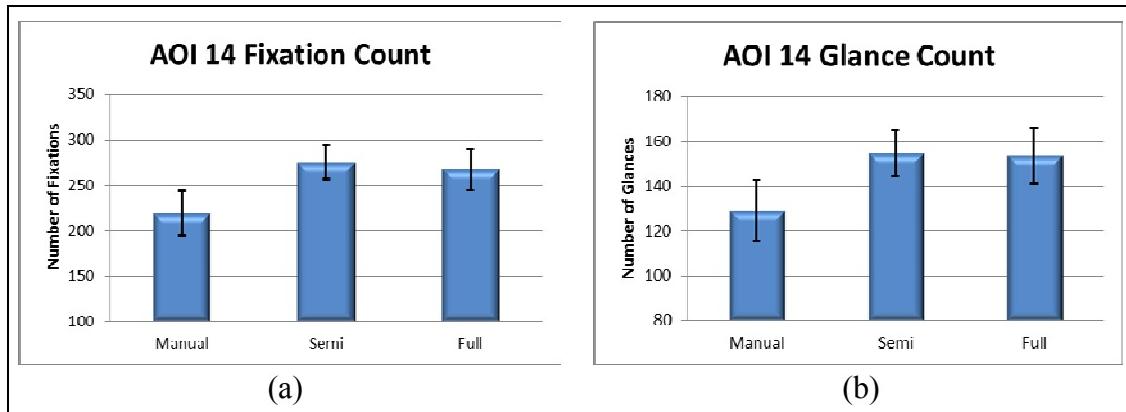
Figure I-30. AOI 14 fixation count (a) and glance count (b), across LOAs.

There was a marginally significant main effect of LOA on Average Glance Duration in AOI 14, Wilks' $\lambda = 0.822$, $F (2, 28) = 3.040$, $p = 0.064$, *partial $\eta^2 = 0.178$* (figure I-31), but no significant effect on Average Fixation Duration, Wilks' $\lambda = 0.928$, $F (2, 28) = 1.087$, $p = 0.351$, *partial $\eta^2 = 0.072$.* Average Glance Duration in AOI 14 was significantly shorter in the Manual condition than in the Semi-Autonomous or Fully Autonomous conditions.
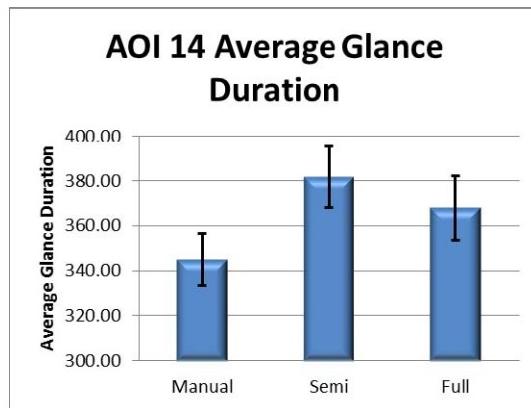
Figure I-31. AOI 14 average glance duration
across LOAs.

I.18.2 Individual Difference Factors

Fixation Count, Glance Count and Average Glance Duration in AOI 14 were negatively correlated with PAC in the Manual condition (table I-35), but not in either RoboLeader condition. Average Glance Duration in AOI 14 was moderately correlated with SpAC in the Manual condition (table I-36), but not in either Semi-Autonomous or Fully Autonomous conditions. Fixation Count and Glance Count were negatively correlated with SpAC in the Fully Autonomous condition, but not in either Manual or Semi-Autonomous conditions. Average Glance Duration in AOI 14 was negatively correlated with SpAO in the Fully Autonomous condition (table I-37), but not in either Manual or Semi-Autonomous conditions. Average Fixation Duration and Average Glance Duration in AOI 14 were negatively correlated with Gaming Experience in the Manual condition (table I-38), but not in either RoboLeader condition.

Table I-35. AOI 14 usage: PAC correlations with fixation and glance behavior by LOA.

Attentional Control					
		Glances Count	**Avg Glance Duration**	**Fix Count**	**Avg Fixation Duration**
Manual	Pearson's r	−0.377[a]	−0.459[a]	−0.401[a]	−0.145
	Sig. (2-tailed)	0.040	0.011	0.028	0.444
Semi	Pearson's r	−0.043	0.083	0.000	0.102
	Sig. (2-tailed)	0.823	0.664	1.000	0.591
Full	Pearson's r	−0.009	0.172	0.060	0.111
	Sig. (2-tailed)	0.962	0.364	0.752	0.560

[a] Correlation is significant at the 0.05 level (2-tailed).

Table I-36. AOI 14 usage: SpAC correlations with fixation and glance behavior, by LOA.

Spatial Ability Cube Comparison (SpAC)					
		Glances Count	**Avg Glance Duration**	**Fix Count**	**Avg Fixation Duration**
Manual	Pearson's r	−0.293	0.331	−0.273	0.293
	Sig. (2-tailed)	0.117	0.074	0.145	0.116
Semi	Pearson's r	−0.111	0.242	-0.067	0.163
	Sig. (2-tailed)	0.559	0.198	0.724	0.388
Full	Pearson's r	−0.444[a]	−0.031	−0.422[a]	-0.021
	Sig. (2-tailed)	0.014	0.870	0.020	0.914

[a] Correlation is significant at the 0.05 level (2-tailed).

Table I-37. AOI 14 usage: SpAO correlations with fixation and glance behavior by LOAs.

Spatial Ability Orientation (SpAO)					
		Glances Count	**Avg Glance Duration**	**Fix Count**	**Avg Fixation Duration**
Manual	Pearson's r	0.235	−0.244	0.141	0.026
	Sig. (2-tailed)	0.212	0.193	0.456	0.892
Semi	Pearson's r	0.184	−0.249	0.042	0.091
	Sig. (2-tailed)	0.331	0.185	0.825	0.633
Full	Pearson's r	0.142	−0.368[a]	−0.006	−0.039
	Sig. (2-tailed)	0.455	0.045	0.973	0.838

[a] Correlation is significant at the 0.05 level (2-tailed).

Table I-38. AOI 14 usage: gaming experience correlations with fixation and glance behavior by LOA.

		Gaming Experience			
		Glances Count	Avg Glance Duration	Fix Count	Avg Fixation Duration
Manual	Pearson's r	−0.010	−0.364[a]	−0.032	−0.378[a]
	Sig. (2-tailed)	0.957	0.048	0.866	0.039
Semi	Pearson's r	−0.064	−0.290	−0.135	−0.140
	Sig. (2-tailed)	0.736	0.120	0.477	0.459
Full	Pearson's r	0.278	−0.195	0.222	−0.173
	Sig. (2-tailed)	0.137	0.302	0.239	0.361

[a] Correlation is significant at the 0.05 level (2-tailed).

I.18.3 PAC

There were significant interactions between PAC and LOA on Fixation Count in AOI 14, Wilks' $\lambda = 0.741$, $F(2, 27) = 4.727$, $p = 0.017$, partial $\eta^2 = 0.259$ (figure I-32a), and between PAC and LOA on Glance Count in AOI 14, Wilks' $\lambda = 0.748$, $F(2, 27) = 4.543$, $p = 0.020$, partial $\eta^2 = 0.252$ (figure I-32b). Participants with high PAC had significantly fewer Fixations and Glances in Manual condition than those with low PAC, but roughly the same amount of Fixations and Glances as those with low PAC in the Semi-Autonomous and Fully Autonomous conditions.
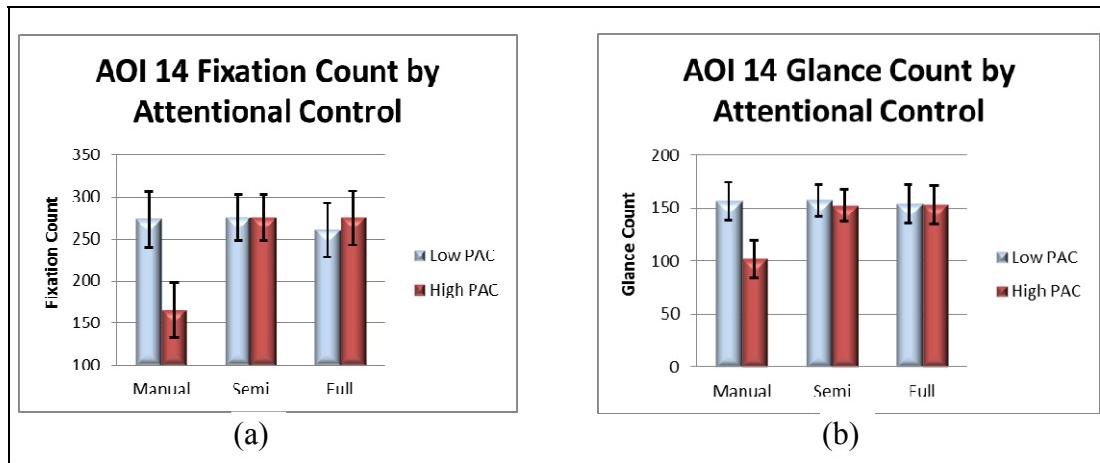
Figure I-32. AOI 14 fixation count (a) and glance count (b) by PAC (PAC), across LOAs.

There was a significant interaction between PAC and LOA on Average Glance Duration in AOI 14, Wilks' $\lambda = 0.755$, $F(2, 27) = 4.388$, $p = 0.022$, partial $\eta^2 = 0.245$ (figure I-33). Participants with high PAC had significantly shorter Glances in Manual condition than those with low PAC, but roughly the same length of Glances, as those with low PAC in the Semi-Autonomous and Fully Autonomous conditions.
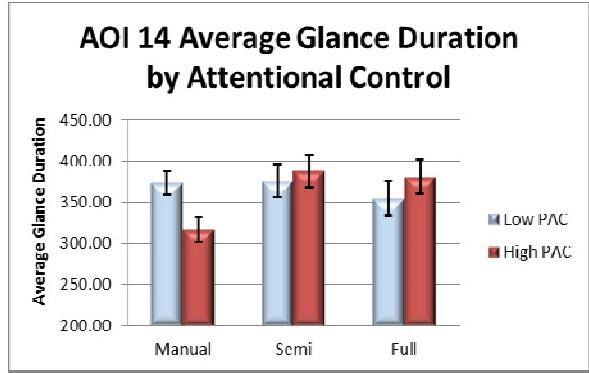
Figure I-33. AOI 14 average glance duration by PAC,
across LOAs.

I.18.4 SpAC

There was no significant interaction between SpAC and LOA on Fixation Count in AOI 14, Wilks' $\lambda = 0.899$, $F(2, 27) = 1.509$, $p = 0.239$, *partial $\eta^2 = 0.101$*, or between SpAC and LOA on Glance Count in AOI 14, Wilks' $\lambda = 0.891$, $F(2, 27) = 1.651$, $p = 0.211$, *partial $\eta^2 = 0.109$*. There was no significant interaction between SpAC and LOA on Average Glance Duration in AOI 14, Wilks' $\lambda = 0.874$, $F(2, 27) = 1.954$, $p = 0.161$, *partial $\eta^2 = 0.126$*. There was no significant between-subjects effect of SpAC on Average Glance Duration in AOI 14, $F(1, 28) = 1.364$, $p = 0.253$, *partial $\eta^2 = 0.046$*. There were marginally significant between-subjects effects of SpAC on Fixation Count, $F(1, 28) = 3.905$, $p = 0.058$, *partial $\eta^2 = 0.122$* (figure I-34a), and on Glance Count in AOI 14, $F(1, 28) = 4.121$, $p = 0.052$, *partial $\eta^2 = 0.128$* (figure I-34b). Participants who scored high in SpAC had significantly fewer Fixations and Glances in AOI 14 than those with low SpAC scores across all mission conditions.
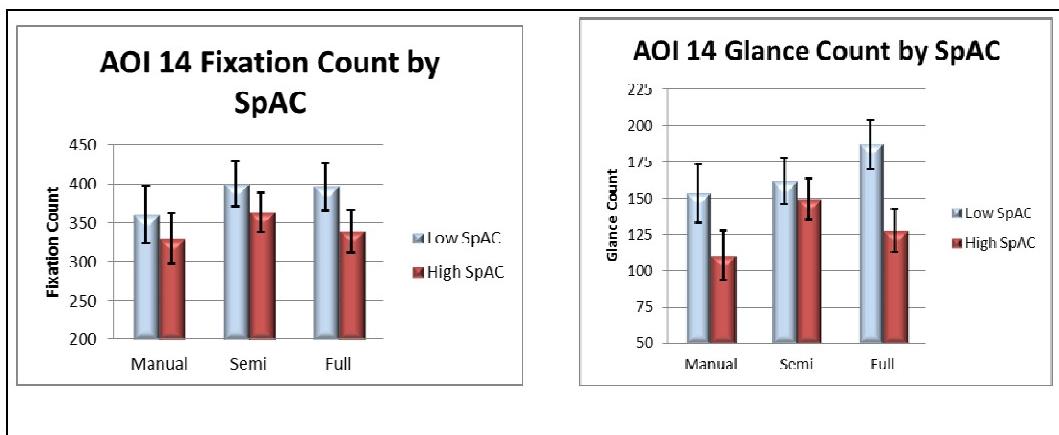
Figure I-34. AOI 14 fixation count (a), and glance count (b) by SpAC, across LOAs.

I.18.5 SpAO

There was no significant interaction between SpAO and LOA on Average Glance Duration, Wilks' $\lambda = 0.965$, $F(2, 27) = 0.483$, $p = 0.622$, *partial $\eta^2 = 0.035$*. There was a significant between-subjects effect of SpAO on Average Glance Duration in AOI 14, $F(1, 28) = 4.442$, $p = 0.044$, *partial $\eta^2 = 0.137$* (figure I-35). Participants who scored high in SpAO had significantly shorter Glances in AOI 14 than those with low SpAO scores across all mission conditions.
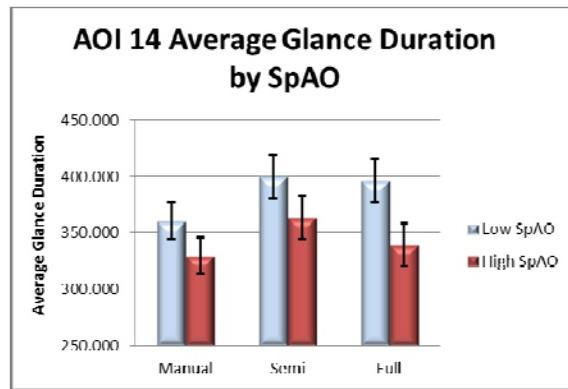
Figure I-35. AOI 14 average glance duration by
SpAO, across LOAs.

I.18.6 Gaming Experience

There was no significant interaction between Gaming Experience and LOA on Average Fixation Duration, Wilks' $\lambda = 0.897$, $F(2, 27) = 1.548$, $p = 0.231$, *partial $\eta^2 = 0.103$*, or between Gaming Experience and LOA on Average Glance Duration, Wilks' $\lambda = 0.987$, $F(2, 27) = 0.177$, $p = 0.839$, *partial $\eta^2 = 0.013$*.

There was a marginally significant between-subjects effect of Gaming Experience on Average Glance Duration in AOI 14, $F(1, 28) = 3.985$, $p = 0.056$, *partial $\eta^2 = 0.125$* (figure I-36), but not on Average Fixation Duration, $F(1, 28) = 1.872$, $p = 0.182$, *partial $\eta^2 = 0.063$*. Frequent Action Gamers had significantly shorter Glances in AOI 14 than All Other Gamers across all mission conditions.
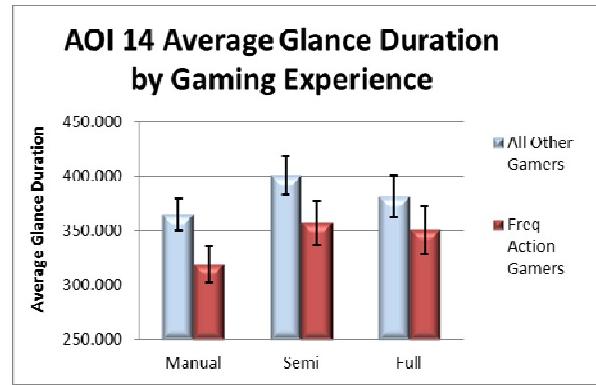
Figure I-36. AOI 14 average glance duration by
gaming experience, across LOAs.

I.18.7 Clicking Behavior

Clicking Behavior in AOI 14 was not correlated with performance on the Target Detection Task
or reported FAs in any Mission condition, nor was Clicking Behavior correlated with any
individual difference measures. Overall, 64% of participants did click in AOI 14, with this
percentage being lowest in the Manual and Semi-Autonomous conditions (60%), and highest in
the Fully Autonomous condition (73.3%), (figure I-37).
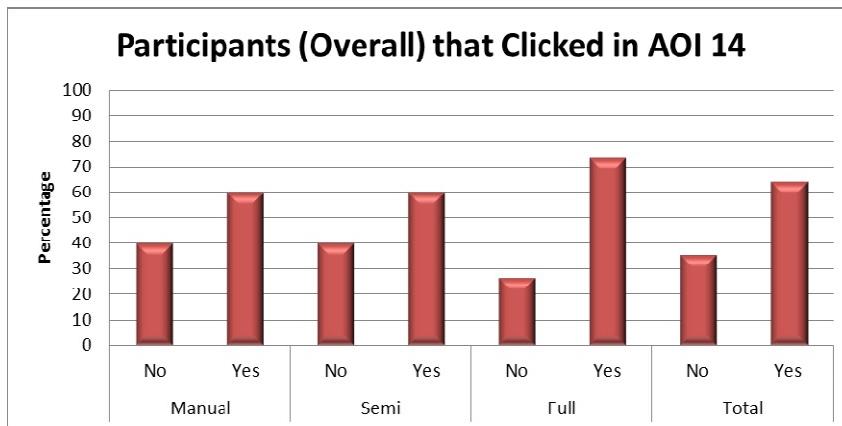
Figure I-37. Percent of participants that clicked in AOI 14 at least once, across
LOAs.

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Appendix J. Participant Comments from the Usability and Trust Survey

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This appendix appears in its original form, without editorial change.

Participant comments as written on the Usability and Trust survey, comments section:

- "Provide zoom capability for UGV camera so the user could make better use of it."

- "Would like auditory feedback when clicking on threats"

- "UAS was not useful. UGV was a little useful, but not much. Pace was slow enough for just the MGV [camera feeds]."

- "Threats were visible from a longer distance, but not clearly rendered and easily identifiable."

- "UAS felt useless, MGV too warped in the periphery. UGV was great, RoboLeader was great."

- Waypoints on top of one another could not be clicked on separately.

- "Hardly used UAS, but UGV and MGV were useful"

- To the question 'The RoboLeader system has integrity', "I'm not sure until that can be proven over time."

- "Allowing the human id targets rather than id'ing and path planning would add a great deal of security to a mission."

- To the question 'The RoboLeader system may have harmful effects on the task,' "I feel it could with terrain choices, but I personally never had to reroute it." "Taking too much control away (i.e. routing, spacing) leaves the user less spatially aware and more concerned with flagging threats which can be harmful depending on the priorities of the task."

List of Symbols, Abbreviations, and Acronyms

ANOVA   analysis of variance

AOI   area of interest

DV   dependent variable

FA   false alarm

FPS   first-person shooter

GE   gaming experience

HRI   human-robot interaction

LOA   level of autonomy

MGV   manned ground vehicle

MIX   mixed initiative experimental testbed

NASA   National Aeronautics and Space Administration

OCU   operator control unit

PAC   perceived attentional control

RED   remote eyetracking device

SA   situation awareness

SMI   Sensomotoric Instrument

SpA   spatial ability

SpAC   spatial ability – cube comparison test

SpAO   spatial ability – spatial orientation test

UAS   unmanned aerial system

UGV   unmanned ground vehicle

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